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Future Transportation Technologies

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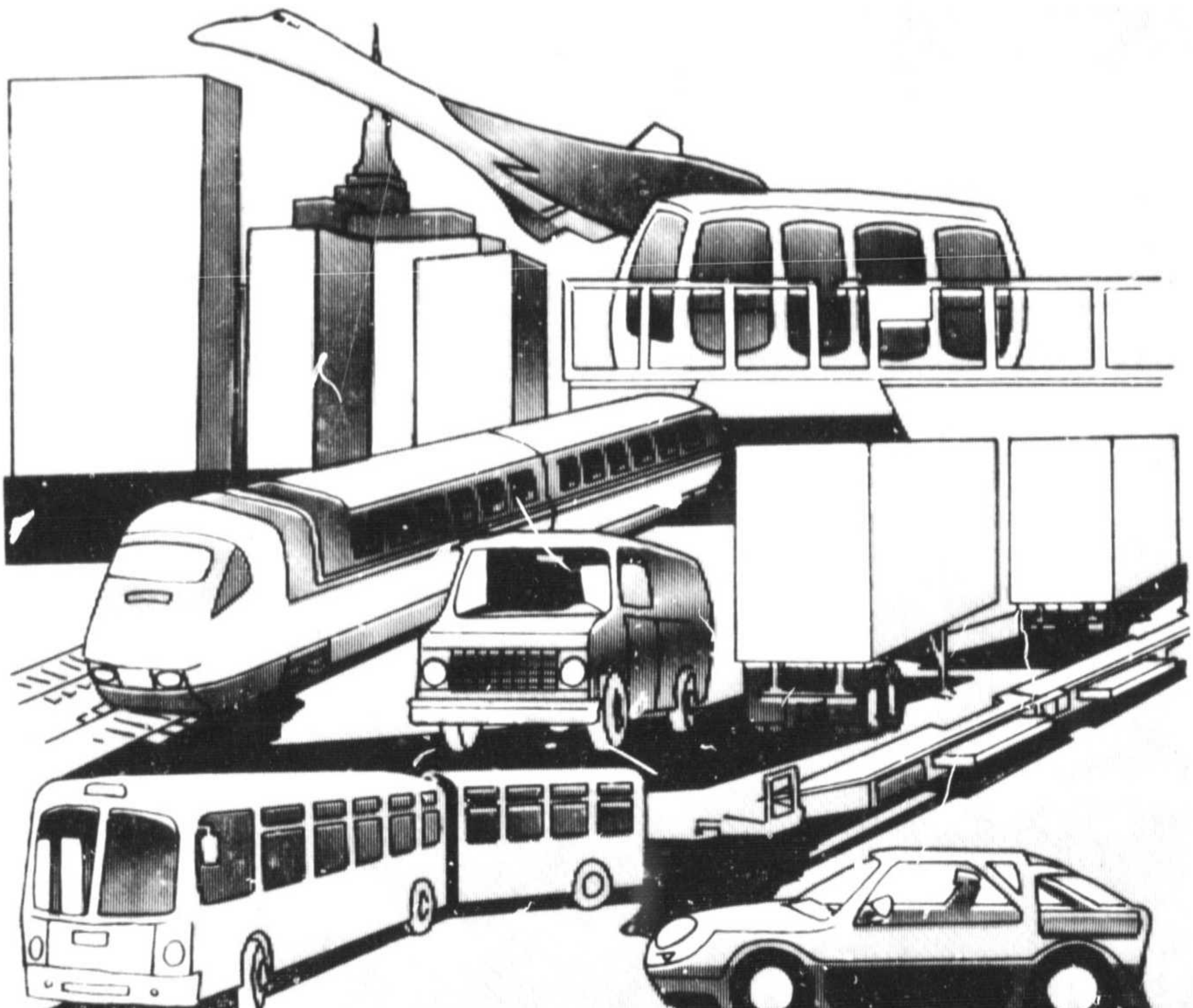

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16. Abstract

This report is a broad survey of currently emerging and possible future technological developments in transportation. It is designed primarily for state and local governments and discusses major topics as the transportation environment, urban public transportation, small city and urban passenger transportation, the private automobile, intercity passenger transportation, cargo transportation and space transportation. This overview of technologies provides time to become more sophisticated in understanding changes that are taking place and the state and local governments will ultimately have to participate in some form in the future. All of these writeups have been based on evolutionary developments from existing technologies. A true breakthrough in any of these fields could redirect the course of transportation futures.

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Contents

Preface

This report is a broad survey of currently emerging and possible future technological developments in transportation. It is an update of a document originally issued in January 1979 and is designed primarily for officials in state and local governments. The report is intended to be comprehensible and useful to an intelligent, nontechnical audience. While transportation technology is treated somewhat comprehensively, extra detail has been provided on topics of special interest to state and local officials, reflecting some of their most frequently asked questions. Treatment of these topics is also somewhat conservative in that the development and implementation of technologies are dependent on many factors (technological, fiscal, economic, institutional, political, and social) and thus cannot be projected with any certainty. It is important, however, to understand what could be, so that planning for the future takes into account the many possible options and systems.

The document is not, and should not be considered to be, a study of alternative transportation futures. In such a study, a coherent set of alternative socioeconomic assumptions is presented, and future transportation developments are traced, along with the impacts which result from them. Transportation events will occur under some socioeconomic circumstances that will not occur under others. A substantial number of these alternative events will result from policy choices made by state and local officials.

While the majority of the technologies described will be applied over the next 10 to 20 years, some, such as hydrogen-fueled hypersonic transports and tracked levitated vehicles, will not be introduced commercially in this century. In addition, demonstrations or pilot tests are typically conducted before new technologies enter general applicability.

It should be noted especially that the nontechnical and institutional factors frequently have more impact on the ultimate implementability of an innovation than has pure technical feasibility. The availability of resources at any level of government is limited, and there are a variety of ways these funds might be spent. In addition, the productivity and viability of existing systems may often be improved in ways that do not involve extensive investment in new hardware. These facts should be taken into account when considering any of the options described here. Therefore, this document is intended to be informative, not prescriptive.

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Summary

The characteristics of future transportation systems will be determined, in large part, by the missions they must serve, the resources that are available for their deployment, and by the broad environment which they will be entering. Because of a decreasing labor pool of young and middle aged Americans, demographic shifts may place added emphasis on automated systems after the year 2000. Increasing growth in small towns also implies an emphasis on systems to serve low-density, suburban, and rural areas. Energy constraints may make electrically powered systems more attractive.

Whatever America's urban future, future urban transportation systems will probably consist of some mix of transportation options working together. These systems could include technologically upgraded versions of existing options, as well as new technologies. Bus systems to serve rural or exurban areas are also developing, and they may be tied into evolving urban systems. Taxi operators and intercity bus lines can also play a role in this.

The passenger automobile, or a similar option, will probably retain dominance of the transportation scene. Its flexibility and personally tailored service are unrivaled by any common-carrier options currently known. Design changes have already resulted in more fuel-efficient automobiles, and new engine technologies also appear promising in the long term (post-1985).

Energy shortages may necessitate more reliance on common carriers such as intercity rail or air systems, with buses serving lower density routes. After the turn of the century, tracked levitated vehicles (TLVs) may eventually replace the high-speed trains operating on some high-density routes.

More energy-efficient jet transports, as well as a new breed of short-range, short-takeoff aircraft, should be entering service in the 1980s. These could include high performance propeller aircraft. Supersonic, hypersonic, and lighter-than-air aircraft may also have long-term applicability. The availability of these new air options could also support growth in low-density areas, especially by commuter carriers. Alternate fuels for aircraft, such as liquid hydrogen, could be a possibility for aircraft in the mid- to late-1990's.

Cargo systems will also evolve. Truck and freight systems are consuming an ever increasing percentage of petroleum fuels. Trucks are being built larger, and they incorporate modifications to make them more energy efficient. Containerization and automated freight handling should improve the compatibility of motor carriers with rail and air freight systems. Large intermodal freighters and tankers serving deepwater ports may appear on sea routes. New pipeline technologies are also emerging.

The space shuttle will enter service in the early 1980s and make major changes in the way orbital missions are approached. Construction projects in orbit, including concepts such as solar collection satellites or space manufacturing centers, become much more feasible.

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Chapter 1
The Transportation Environment

It is always difficult to speculate intelligently or accurately about the future, especially in an area as sensitive to technological change as transportation. Historically, many transportation technologies have risen, have had extensive periods of application, and have declined as new systems took their place. In some cases, such as highways, breakthroughs in construction techniques and in new types of vehicles allowed the system to continue to grow. In other instances, such as canals, competition for more effective and efficient modes for the same mission lead to obsolescence and ultimate decline. The history of transportation is a history of how to apply (or not to apply) technologies.

In addition, *technology*, as applied to transportation, can refer to a wide range of things:

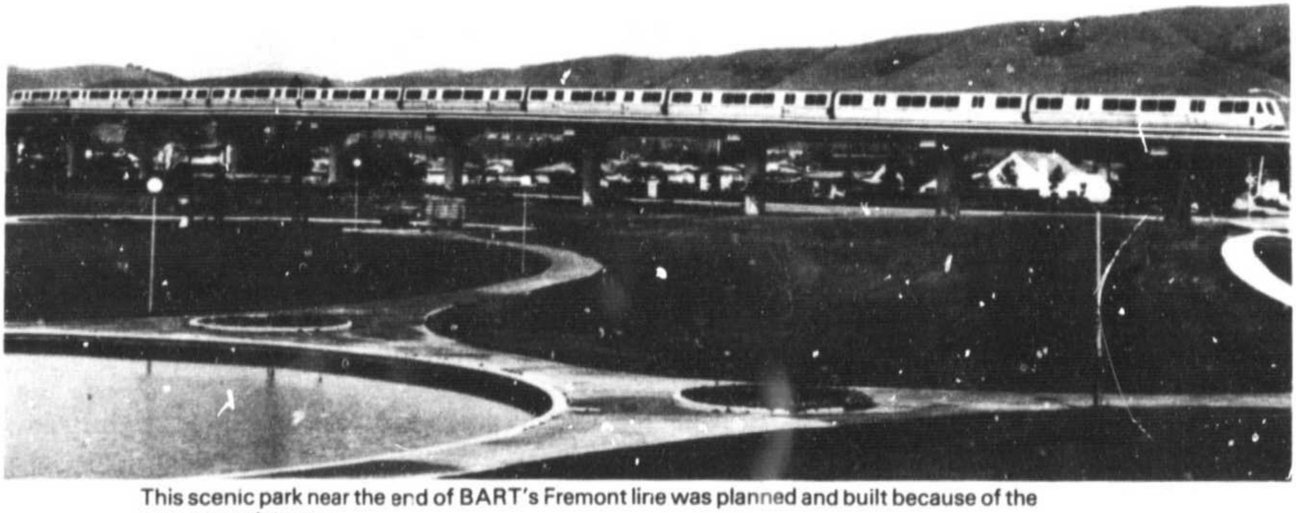
- Hardware (such as a new type of suspension system for an auto, bus, or rail car),
- Software (such as a computer package used to control a system),
- Operational Improvements (such as a new way to route buses),
- Management Improvements (such as a new technique to finance a system).

Transportation is rather unique, for it borrows its technical tools from almost the full range of human knowledge.

A tremendous number of economic, sociological, and technical factors interact to determine whether a new technology will persist. If one lesson can be learned from transportation history, it might be that any new technology has to fit the applications defined for it. The personal helicopter, the flying platform, and automobiles that would convert into airplanes were all proposed as options for general use, but they failed to gain any widespread popular acceptance.

As a technology evolves, it has to be developed and tested adequately before it is deployed, or it might not gain acceptance. The British Comet Jetliner was introduced in the early 1950s, but it went into only limited use at that time because of structural problems. Turbine-powered airliners were accepted as a practical alternative for air carrier service only after the Boeing 707, a proven adaptation of the U.S. military KC-135 tanker, entered service in the late 1950s. From that point, it took less than 10 years until jets essentially dominated the entire field of commercial aviation. The quick adoption of turbine powerplants in commercial aviation points up the pervasive impact of a true breakthrough.

Of course, the acceptance of any innovation is very dependent upon the environment that it is entering. Technicians have not been particularly



This scenic park near the end of BART's Fremont line was planned and built because of the presence of the line.

successful in forecasting future value systems or standards, and these values set the benchmarks by which new systems are judged. This may have contributed to the lack of adoption of some "innovations" by their supposed users. We can safely say that transportation must be a good neighbor and compete favorably with other choices for investment, whether by the private sector or by government.

Many of the factors shaping the transportation system of the future have already emerged, and they will have profound effects over the next 20 to 30 years. Although not immediately connected with transportation itself, these broad concerns determine the missions of future systems, their technical practicality, their economic feasibility, and the availability of funds for deployment. Some of the major trends will be discussed in the following sections.

GENERAL DEMOGRAPHICS AND TRAVEL IMPLICATIONS

The majority of the people who will be American adults in the early 2000s have already been born, so it is possible to make some general statements about population during that period. If population growth is consistent with Census Series III projections (1.7 children per female through the year 2000), U.S. population should stabilize near 250 million in the late 1990s.(67) Shortly thereafter, a major shift in the available labor force should occur as people who were born in the rapid population growth period of 1945–55 begin to retire. With these assumptions, the proportion of people over 65 will increase to some 16 percent of total population by the early 2000s, compared to their 10 percent of total U.S. population in the 1970s.

A population growth spurt in the next two decades might blunt this aging effect somewhat, but there should still be some increase in the relative number of elderly. This spurt may result if recent lower birth rates came from decisions to defer having children rather than from decisions not to have them at all. An increased retirement age (70–75) might also blunt the economic effects of the trends.

Geographically, demographers have noted a major migration to the sunbelt states of the Southwest and Southeast. Especially in the Southeast, water and resources are plentiful, making these states attractive as new manufacturing centers. The warm climate of these states has made them attractive as winter retirement communities. There is strong evidence that the trend will continue, especially in view of the increasing proportion of elderly people in the population. Some observers have also pointed out a migration from inland areas to coastal zones, but this shift has not been defined as precisely as the sunbelt trend.

Simultaneously, there have been some basic changes in the pattern of urbanization over the last hundred years. The early 1970s indicated a major resurgence of growth in rural areas. Much of this growth occurred in counties contiguous to Standard Metropolitan Statistical Areas (SMSAs), suggesting this development might be properly described as small town growth. However, there have been growth increases in many small towns and smaller urban areas in counties not contiguous to SMSAs. People who have moved out of major urban centers frequently indicate dissatisfaction with the pace and life style of the larger cities and a general uneasiness about the effectiveness of large-scale institutions in dealing with urban problems.(34)

Early analyses of the 1980 census data performed by the U.S. Department of Agriculture's Economics and Statistics Service indicate that the population growth rate in rural communities and small towns is now higher than that in larger cities and their suburbs. Growth in rural areas was some 15.4 percent nationwide during the period 1970 to 1980, as contrasted to a 9.1 percent figure for metropolitan areas. Nonmetropolitan growth was especially rapid in the West, averaging more than 30 percent.

The urban-suburban growth trends which dominated the middle part of this century have changed somewhat, but a tremendous amount of capital has already been invested in the metropolitan areas and suburbs, and these facilities and housing will persist. In addition, the character of some cities has been changing through "gentrification" as middle and upper income people move back to center city areas, often to refurbished townhouses or older buildings. This does not necessarily indicate total reversal in outmigration trends, but it does result in revitalized spots. These increasingly complex demographic trends imply an added level of technical sophistication to meet the travel requirements of dense neighborhoods, low-density areas, and the other elements of the complex development patterns they have spawned.

A 1980 DOT analysis attempted to assess the travel implications of recent growth trends.(57) The analysis noted that over 80 percent of the housing units that will be occupied in 1990 already exist. Over 25 percent of these households are located in the suburbs of major cities and have been developed at suburban densities. These housing units, developed when automobile travel was

Some cities have experimented with transit malls, such as this one in Minneapolis, Minnesota.

rather cheaply priced, will continue to be occupied for the foreseeable future.

Physical constraints such as street patterns and institutional constraints, including zoning regulations, building codes, and lot sizes, inhibit any transition to land use patterns which might be served more efficiently by means other than the private automobile. Small lot development and higher densities along transit corridors could influence suburban auto use significantly.

Over the next two decades, many households will consist of a single—often elderly—person, unmarried individuals, or married couples without children. Since the number of households is increasing and the average household size is decreasing, these trends may reduce average vehicle occupancy and have other transportation effects as well. The residents of these households are likely to be less concerned with schools or child-oriented recreation than with adult-oriented recreation such as restaurants, theaters, sports complexes, or social clubs. The trend might prove beneficial to central cities, which provide an environment more appropriate to such an adult culture.

The demand for travel during the 1980s is expected to grow at a rate faster than population but slower than households. The rate of travel growth should be slower than that observed over the past 20 years. The largest growth in the number of trips will probably occur in central cities, paralleling the growth in households. Travel by transit, as a proportion of total travel, is likely to remain fairly constant as the number of central city households grows. The result will be a significant increase in the total number of transit trips. Unless there is a substantial redistribution of transit travel from peak (morning and evening rush) to off-peak times, or productivity improvements are made, this added demand will continue the trend of growing transit deficits.

Total vehicle-miles of travel (VMT) will increase about 20 percent during the 1980–1990 period. However, due to the differing rates of travel for central city and suburban households, the distribution of VMT by area will be similar to that of 1980.

ENERGY AND RESOURCES

The U.S. transportation system, particularly its highway elements, was set in place during an era when tapped energy sources were plentiful and prices were low. Transportation was a necessary feature for wide-ranging development patterns. Such a spatial structure may be affected more by energy shortages than transportation systems in older countries, where tighter development patterns are typical. In any case, it is now generally understood that there is a limited supply of many of the key energy sources on which the current highway transport system has been based.

In addition to the impacts of a limited fuel supply itself, the 50 percent of all petroleum products that are used in transportation are significantly affected by the use patterns of automobiles, light-duty trucks, and heavy trucks or buses. Total petroleum consumed by freight carriers is increasing. However, while some fuel economies have been achieved in motor carrier operation, greater economies have resulted with automobiles as a result of the public's selection of more fuel efficient cars, trip planning, better maintenance, and increased use of fuel-efficient driving techniques.

The whole issue of energy supply and the alternate ways it might be used may place constraints

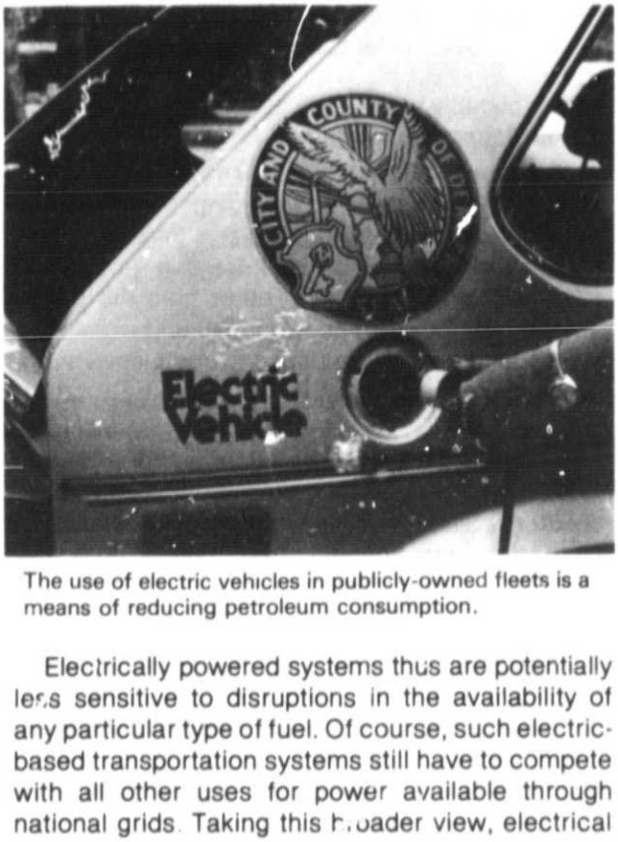
on the future evolution of urban, rural, interregional, and international transportation systems. Since the course of future transportation systems (and society in general) is heavily dependent on energy and resource availability, it might be well to examine this subject in more detail. Three general scenarios have been discussed by policy makers:

1. *Business as Usual*, in which there is a continued availability of cheap liquid fuel or mobile sources, such as improved batteries. The result would be more rapid, convenient, and personal transportation along with a more dispersed population.
2. *Transition*, in which energy sources are switched gradually from petroleum as prices rise. This implies heavy dependence on coal or nuclear-generated electricity in the next 10–20 years and appropriate rearrangements in urban and suburban ways of life.
3. *Restricted Supplies*, in which costs for current fuels rise drastically because substitute sources are not available. Associated with this might be total and per-capita energy use decreases and massive changes in transportation and societal organization as the nation readjusts, painfully but successfully.

These scenarios, which cover a range of plausible outcomes, have dramatically different transportation futures associated with them. For example, barring some major technological breakthrough such as nuclear fusion or substantial cost reductions in solar capture technology, energy under a restricted supply scenario could cost substantially more. These costs would have to be passed on by industry to consumers. Costs could include both increases in the prices of conventional petroleum sources as competition for them becomes more intense, and capital costs associated with the construction or installation of new facilities designed to utilize energy from non-petroleum sources. Such projects might include retrofitting electric plants to burn coal, installation of solar collectors or heaters, and large-scale deployment of nuclear fission or fusion powerplants.

With the changing energy situation, electrically powered transportation systems could assume an added importance. An electrically powered system does not have to depend on oil, natural gas, or petrochemicals, since a number of techniques can be used for power generation. Some of the possible alternative power sources, any one of which could be key to transition, include:

1. coal and similar non-petroleum fossil fuels
2. alternative alcohol-based fuels (methanol/ethanol)
3. synthetic fuels (oil shale and tar sands)
4. hydrogen as a fuel
5. solar heat (focusing sun's rays to generate heat in some working fluid)
6. solar photovoltaic (collecting array of solar cells)
7. nuclear fission
8. nuclear fusion (if perfected)
9. geothermal power
10. hydroelectric power
11. tidal power
12. ocean temperature differential power
13. wind power



The use of electric vehicles in publicly-owned fleets is a means of reducing petroleum consumption.

Electrically powered systems thus are potentially less sensitive to disruptions in the availability of any particular type of fuel. Of course, such electric-based transportation systems still have to compete with all other uses for power available through national grids. Taking this broader view, electrical systems still compete with alternatively fueled systems, including those using hybrid fuels, in the demand for shale, tar sands, and coal.

Energy shortages may also influence the pattern of national development over the next few years. For example, migration to sunbelt states may be affected if price increases or controls make the use of home air conditioning equipment prohibitive. Densities in many of these states are also typically lower than those of the current Northeast. In the North, shortages of heating fuels may have similar effects.

On a smaller scale, energy shortages may force a return to more concentrated urban centers if

costs to provide services over today's broad areas become prohibitive. This prospect has contributed to renewed interest by many cities in downtown revitalization and higher density development patterns. This approach to downtown growth also leads to pressures to design urban transportation projects to achieve broader goals. Local governments may install or upgrade systems to enhance the environment, add to the architectural beauty of an area, recapture congested areas for better use, or improve community safety, as well as for direct transportation benefits.

Concerns about energy have also led to examination of resources previously taken for granted. There are limits to the world reserves of a number of important minerals and metals, and the United States imports a significant quantity of materials in this category. Dependence on foreign sources has increased not only for oil, but also for bauxite, (93 percent of which comes from foreign sources), chrome (92 percent), platinum (91 percent), tin (81 percent), nickel (71 percent), and aluminum (90 percent). Cobalt, chronium, and tungsten are among other imported metals that are essential to the transportation manufacturing industry.

Higher resource prices may eventually lead to shortages of some strategic raw materials, and cooperative efforts to minimize long-term reliance on these materials may emerge. Technologies based on the use of more plentiful materials thus become more attractive. In addition, new classes of materials, now in the process of development, may be useful in overcoming problems created by shortages.

ECONOMIC IMPLICATIONS

The U.S. economy has become increasingly linked to the world economy. The competition for energy, some natural resources, and capital has become intense. In addition, other developed nations have become highly competitive with the U.S. for the markets of a wide range of industrial products, including transportation-related ones.

In the early 1950s, the U.S. produced more than 75 percent of the world's automobiles—today it produces less than 30 percent. A similar loss took place in tire production. Likewise, in the early 1950s, the U.S. produced more than 50 percent of the world's steel and aluminum—today it produces 20 percent of the world's steel and 25 percent of the world's aluminum.

These losses, in large part, are a result of foreign markets growing faster than those in the U.S. However, the U.S. share of world exports has declined as well. Between 1960 and 1979, America's share of exported manufactured goods declined from more than 25 percent of the world total to about 16 percent. Meanwhile, foreign penetration of the U.S. domestic market continued. Imported car sales in 1979 were the highest in history, with roughly 40 percent of the growing small car world market going to Japanese manufacturers.

Complicating the balance of trade situation is continuing inflation. Even if inflation can be controlled, major transportation system investments in the future will require multiple billions of dollars. At the same time, many authorities have noted a developing need for investment capital across all sectors of the economy. Proposed transportation improvements will have to compete for this capital, along with requirements in all other sectors of the economy. This is true not only for private sector investment, but also for major public projects like urban revitalization.

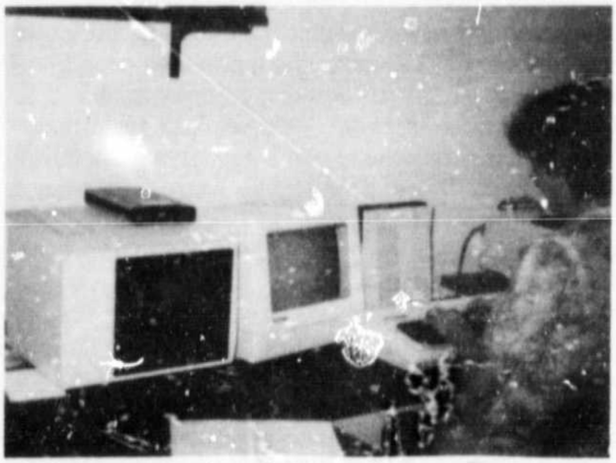
This scarcity of capital may be complicated by the changing demographic balance of the world population. For example, the increasing proportion of elderly people to working people in the U.S. economy after the year 2000 will call for a major increase in productivity of the available work force. To achieve these productivity increases, major expenditures of capital to install automated technologies will be needed. Resolving the competition for available capital among the various investment needs could be one of the more crucial economic problems in the latter part of the twentieth century. It should also be noted that the changing mix of economic activity that might occur will have a direct impact on goods movements, as the types, sources, and destinations of raw materials and completed products change.

Inflationary pressures have already created special emphasis on the need for productivity improvements in all sectors of the economy, including transportation. The average annual productivity growth fell from 2.9 percent in the 1965–73 time period to 0.9 percent in the 1973–78 time period. Because of its exceptionally heavy dependence on petroleum, the transportation sector might be expected to experience a higher rate of inflation than the rest of the economy. Unless solutions are found, continued increases in fuel costs, as well as higher labor costs, may lead either to continuing increases in the price of transportation services or to financial stress within transportation industries.

Options discussed for productivity improvement in transportation include accelerating the government decision-making process and eliminating the burden of regulation and red tape; supporting

selected research and development; encouraging innovation in technology, management, and institutional processes; developing stronger incentives to industry for capital investments; seeking the cooperation of labor in developing work rules that promote productivity; and stimulating intermodal cooperation and development.

The private sector investment and retooling required to produce a new generation of fuel-efficient vehicles and technologically innovative vehicles may be extensive. As with any major program of investments, there must be other large-scale economic effects in different sectors that will result. Associated issues include industry's access to capital and resources, whether government should reward investments in retooling and plant replacement, and streamlining of regulations. There may also be new ways to coordinate public and private sector activities or to develop formal cooperation strategies.



Telecommunication advances will have an impact on future transportation demand.

TRANSPORTATION-TELECOMMUNICATIONS TRADEOFF

In the long term, advances in telecommunications technology may have a substantial impact on the path of evolution that transportation takes. For example, a continuation of the current pace of technological improvement in telecommunications might decrease the demand for transportation to and from the work place by permitting a significant number of workers in information-related business to work at home or in remote centers. Some signs of the feasibility of this approach include the evolution of the home television set into a display for home computer terminals and monitors for playback of videotapes or videodiscs. Relatively soon home televisions may serve as receiving stations for direct transmissions from satellites. If the personal interactions associated with jobs are key elements of job satisfaction, local work centers "linked" to central communication complexes are especially probable. A wide variety of possibilities are open.

The effect of these changes on travel demand is the subject of much speculation. Some commentators argue that telecommunications improvements will eliminate the need for certain types of business travel. On the other hand, other analysts believe telecommunications improvements will stimulate the demand for travel by expanding each individual's range of personal contacts and geographic interests, thus promoting personal and nonbusiness trips.

The U.S. Postal Service may eventually use electronic communications instead of physical transportation of paper to transmit some types of messages between cities. Telecopiers are already in widespread use, and this is merely an extension of the trend. If electronic mail did enter widespread use, it might mean a long-term reduction in the growth of air cargo, and, to a lesser degree, truck movements.

USER PERCEPTIONS AND ATTITUDES

The opinions and views of individual Americans will have a lot to do with the acceptance of new systems and options. The Department conducted a major survey of American attitudes toward transportation in 1978.(39) This study provided some basic indications of what kinds of changes and evolutionary developments would be accepted by the American public.

In general, the public expects some basic changes to occur in the national way of life over the next few years. They favor proposals which increase the number of transportation options open to them, and they have a distaste for "mandatory" solutions such as gas rationing. There is a consensus that the automobile must be used in a more energy-conscious way.

According to the survey, American people also seem to support evolution and growth of public transportation relative to highways. There are indications that the more innovative concepts of transit service, such as park-and-ride lots and feeder routes to buses, would be especially well received. There also appears to be significant potential for carpooling, especially if special treatment is given to multi-rider cars on the streets to cut travel time.

Over the long term, these perceptions and judgments may change. However, these kinds of public acceptance considerations have to be factored into the planning for any future systems. Those affected by proposed changes typically want to be consulted before any changes are implemented.

Chapter 2
Urban Public Transportation

URBAN ENVIRONMENTS

Urban transportation requirements in the future will be determined in large part by the operational environments in which they must function. The public transportation system needed to serve a spread-out, heavily suburbanized metropolis is technologically different from that needed to serve a dense, centralized urban complex. There are a number of plausible urban futures, each having its own unique set of transportation problems and system requirements. Some of these include the following:

- *Urban Decline*—There has been a pattern of decline noted at the core of many large cities. A conscious decision to allow a large city to decline and to emphasize service to close-in dense areas and suburban activity centers would produce, in its extreme, a donut-like cluster of population and business concentrations with the center essentially abandoned. Some people find that this option is undesirable because of the major loss of fixed facilities it implies and the end of the downtown-cosmopolitan life style in cities where it occurs. This policy is probably unlikely unless forced by major resource shortages.
- *Urban Revitalization*—Many urban planners hold that the downtown decline pattern is reversible. If this view is accepted by political leaders, local policy initiatives may be developed to encourage revitalization of, and new development in, downtown areas; these initiatives could be coupled with programs to make center city life style more attractive. The result of such initiatives would be dense, compact central areas with higher populations and a greater need for the good circulation systems currently required by urban centers. Over a longer period, some futurists see areas of this type evolving into "megastructures," with all inhabitants living in one huge complex of interconnected buildings. While there are complex design problems associated with this approach, proponents find this life style attractive and claim there is a potential for major energy savings by supporting this developmental concept.

Buses are a major transportation element of revitalized downtown areas.

- *Continued Current Trends*—The most likely urban development alternative is a hybrid of the above two approaches. Major efforts would be made to save the center city while suburban growth would continue. This policy projects a continuation of current growth trends with some improvement in downtown conditions and a greater integration of downtown and suburban activities. Regional transportation would be especially important if this occurs, since people would begin again to view the center city as a useful activity center, but not necessarily as a home. The demographics of the 1980–2000 time period would seem to support such an approach in some areas.

- *Urban Decentralization*—Another possibility is a further growth spurt in small and medium-size cities, accounting for most of the national population growth, with some contraction of large cities as population loss occurs. In the U.S., this trend may be especially important if people leave large cities in the Northeast to resettle in new smaller cities of the South or West. A spreading out of population would imply more emphasis on shorter-range, medium-capacity systems and circulation requirements. In a related area, it would require more sophisticated telecommunications networks to transmit data between the various centers. This might lessen the need for routine long-distance business travel.

Because of variations in local policies, all of these scenarios may manifest, to some degree, the specific course of evolution for any city being determined by local conditions and policy decisions.

SYSTEM OPTIONS

Urban transportation planners have a wide variety of options, each with its own cost and operational characteristics, and each capable of providing specific types of service.

Paratransit Systems

Paratransit is a general term for the spectrum of service options between the private automobile and fixed-route, fixed-schedule buses. These services include (among others) shared-ride taxis, carpools and vanpools, jitneys, subscription buses, and demand-responsive buses. For many of these alternatives, operating policies can be varied to adjust service to changing travel patterns and demand. Paratransit elements thus enable an operator to provide special, personalized service in areas where it would otherwise be impossible. They should be a key component of future urban systems, especially in lower density areas.(72,74)

At least three major applications for future paratransit options can be identified:

- Paratransit, especially dial-a-ride or demand-responsive service, shows great promise of extending transit service to the lower density suburban areas of large cities. Flexible-route buses can serve low levels of travel demand far more economically than can the extension of conventional fixed-route bus transit into low density suburbs.

Paratransit vehicles like this prototype may find extensive use in future cities and suburbs.

- Paratransit can provide circulation service in dense downtown areas. Typical of this type of operation are jitneys, small vehicles which operate on fixed downtown routes and which can be hailed by passengers anywhere along the route. Jitneys have been used successfully in such cities as Mexico City and Manila. Fixed-route circulation minibuses can operate in a similar manner, substituting conventional bus stops for the hailing technique used by jitneys.

- Paratransit can be used to provide special transportation services to groups such as the handicapped or the elderly. For these applications, special modifications may be necessary, such as extra-wide doors, lifts for wheelchairs, and special seating configurations. It is also desirable for the drivers of such vehicles to have special training or instruction on the problems of mobility-limited users.(81)

Future paratransit services in large urban areas will probably make extensive use of computer or microcomputer routing and dispatch services, both in configuring services to particular needs of their own coverage areas and in tying these services to line-haul bus or rail operations which cover the entire region. The increasing presence of microcomputers will probably have a special impact on the operations of medium-size systems. Computer applications do not appear to be as critical for smaller-scale systems (12 or fewer vehicles). Radio communications will probably be commonplace and may be either on a voice or digital basis.

The vehicles themselves will evolve to fit their specific applications, but it is almost certain that more fuel-efficient engines with lower maintenance requirements are needed. There have been some experiments with battery-powered buses, but major applicability of this approach depends on a breakthrough in low-weight, low-cost, effective batteries. The brakes and suspension system, which have also proven to be critical areas in today's paratransit vehicles, will require improvement.

Line-haul Buses

The full-size 40- to 50-passenger bus is the mainstay of most conventional transit systems, and there is evidence that this dominance will continue. Conventional buses can reach almost any point in the densely populated metropolitan areas by using the extensive highway network. In downtown areas, bus systems can run at capacities of some 10,000 passengers per hour per lane. Theoretical capacity ranges up to some 25,000 passengers per hour per lane are possible with express bus operations on exclusive lanes or busways.

Below a certain demand level, it becomes uneconomical to provide full-size conventional bus service, and a transfer to a local minibus-based paratransit service may become desirable. Research at the U.S. Department of Transportation's Transportation Systems Center (TSC) has indicated this level is approximately 100 passengers per square mile per hour, if 20-passenger minibuses and 50-passenger transit vehicles are being considered for the service.(80)

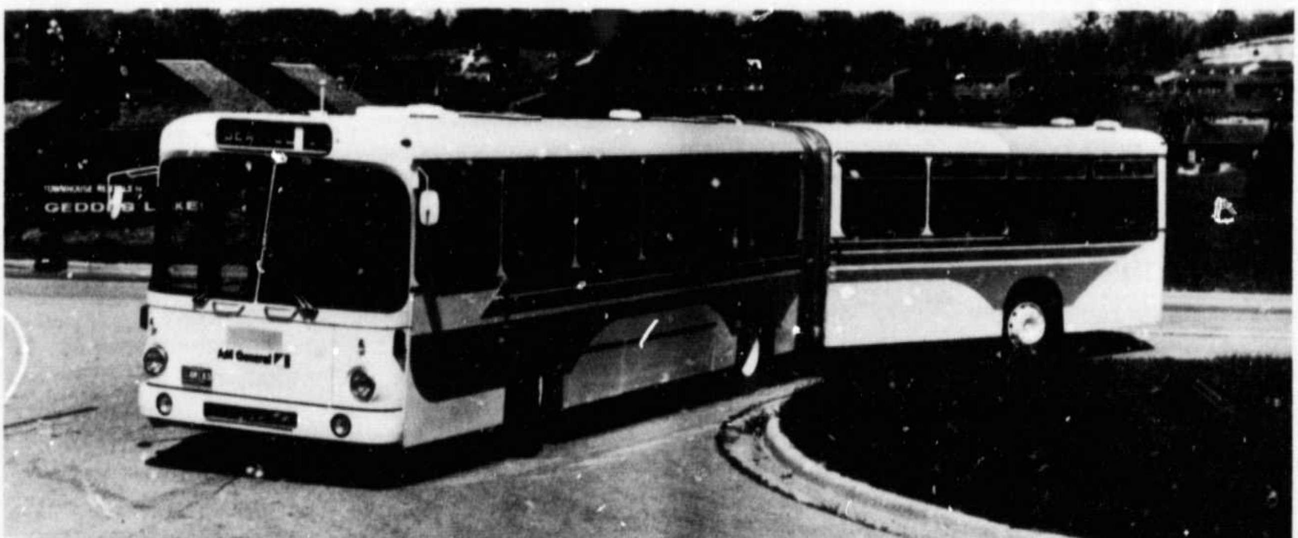
The ability to link transit and paratransit services may lead to the rise of cooperative regional-coverage bus systems. In such systems, paratransit would serve the suburbs and special users, and fixed-route transit would serve downtown areas and activity corridors; express transit on exclusive lanes would link suburban activity centers and downtown areas. As part of automated traffic control, signals may be programmed to give transit vehicles priority over conventional auto traffic, thereby speeding bus flow.(66)

Research efforts in full-size bus development have given special attention to increasing the safety, comfort, efficiency, and public acceptability of buses. Prototype vehicles have been tested to explore whether buses could be built to be more accessible to the elderly and handicapped, more comfortable, more attractive and easier to maintain. Design features of prototype vehicles could be carried over into production of advanced design buses.

A shift to larger size buses may also occur, especially if a downtown recentralization trend occurs or if suburban activity centers become more dense. Such service could be provided by "double-deck" buses or by long, articulated buses with a flexible center section. Double-deck buses, such as those in London, are currently in revenue service in Los Angeles, and articulated buses are now being used in a number of American cities in high-density corridors. Both types of buses may be common features in tomorrow's cities.

Light Rail Systems

For higher capacity systems, cities may consider light rail transit. Light rail transit is a descendent of the old trolley technology, and many systems continue to operate in Europe. Typically, electrically propelled light rail vehicles operate



Articulated buses such as this one are already in service in many cities.

singly or in short trains that are not usually automated. While most of the right-of-way is typically reserved or grade-separated, these systems can also operate at-grade, mixing with highway traffic. However, grade separation is viewed by many U.S. planners as the distinguishing feature of modern light rail. At-grade operation is prevalent in Europe.

Light rail systems can also be used as the first step in upgrading a system to a full-scale, high-capacity rapid rail line. When deployed for this purpose, several design changes would be made from conventional light rail systems, including greater radii of curvature on the guideway, less severe grades, and provisions for later installation of power distribution, control, and platform facilities typical of full-scale rapid transit.(65,75)

San Diego installed a notable light rail system which became operational in 1981. The system, which cost an estimated $5 million per mile, runs a total of 17 miles. The "Tijuana Trolley," as local residents call it, was paid for without any Federal funds.

Rapid Transit or Heavy Rail Systems

Rapid transit systems are considered for the highest urban transportation line capacity levels, up to some 60,000 passengers per line per hour. Vehicles can either operate with steel wheels on steel rails, as is typical with most U.S. rail lines, or with rubber tires in a concrete channel, as with the systems in Montreal, Canada, and Paris, France.

As with the bus systems, two major applications are typical. Lines in downtown areas can help provide circulation service at high capacity levels. Stations are usually closely spaced, and inter-station speeds are relatively low since there is little time to accelerate before braking for the next stop. The downtown segments of Washington, D.C.'s METRO system are built like this. Radial lines may also extend from the downtown into the suburbs along high-density corridors to serve commuter traffic. Station spacing for this application is greater, and speeds are usually higher. Much of San Francisco's Bay Area Rapid Transit (BART) System typifies this latter, commuter-oriented design.

Stations for rapid rail are usually "on-line"; that is, built directly on the main track serving the station, so that the train physically blocks the track through the station when it stops. The other concepts feature "off-line" loading where the vehicles switch onto sidings or spurs off of the main track to load or unload, so that the main line is never blocked during boarding or disembarking.

Rapid rail and other fixed guideway systems are frequently proposed because of their impacts on local development, including the siting of high-rise buildings or business complexes near stations. However, development of a rail system in and of itself has not necessarily resulted in changing urban development patterns. Local zoning and parallel community planning do seem to have a major impact on the success of such policies. In addition, there is always some economic stimulation effect associated with deployment of rapid rail, just as there is with any major public works project.(58)

Future rapid rail systems may depend heavily on automation, both for train control and for support services such as fare collecting. Most modern rail systems are already semi-automated. If regional coverage transit systems become a reality, there should also be closer ties between those rail elements and local feeder systems, which will require better coordination of scheduling between the two.

MARTA train on aerial structure. (Cronk—May 1979)

To improve the energy performance of rail systems, vehicles may be equipped with flywheel energy storage systems. As the vehicle brakes, the flywheels are activated, and the stored energy is then used to help the system accelerate after the stop is completed. Developmental work in materials and construction will make flywheels more reliable and operationally feasible. A proven technology is the electrical regeneration approach, where the vehicle's kinetic energy (energy of motion) is converted to electricity and fed back into distribution lines for use by other trains, as well as for braking the train itself.

Typically, rapid rail systems are quite expensive to deploy. In August 1981, Newsweek magazine quoted costs of $35 million a mile for San Francisco's Bay Area Rapid Transit System, and $64 million a mile for Washington, D.C.'s METRO. The

issues of how to finance installation of a system and cover its operating costs are key concerns which any local official considering the technology has to address.(12).

Automated Guideway Transit (AGT) Systems

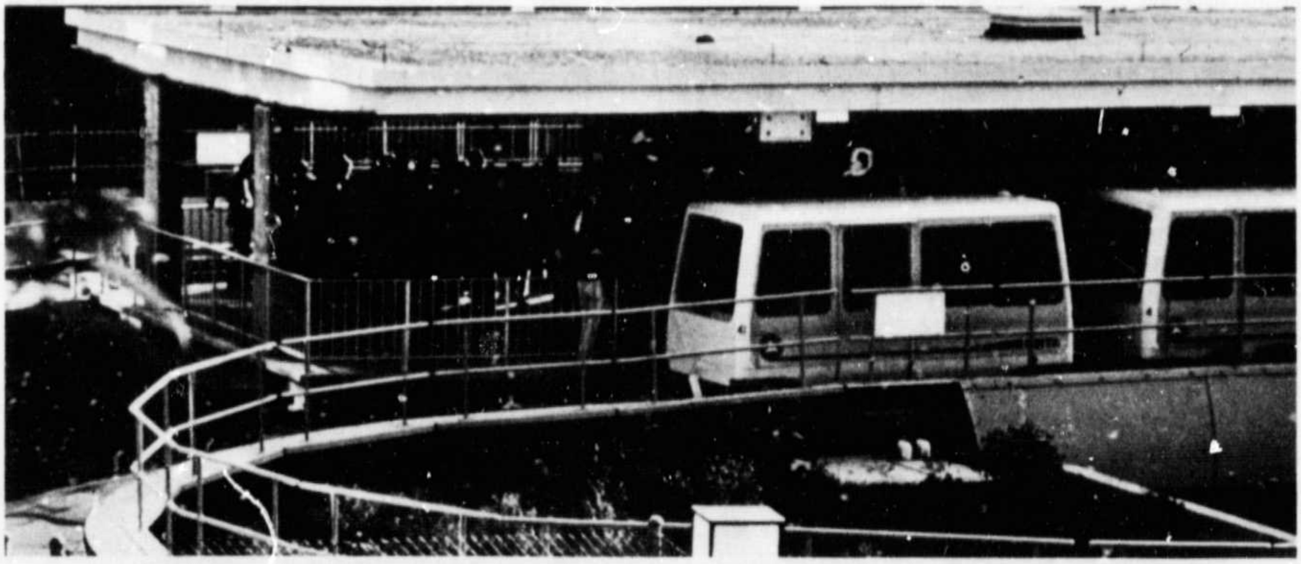
The rise of automated control technologies has made possible a new family of urban transportation systems. These automated guideway transit (AGT) systems, or people movers, may simultaneously provide high line capacities and personally tailored service. There are three levels of sophistication in this technology; each is differentiated by its network complexity and control sophistication.(70)

The simplest kind of AGT system is shuttle and loop transit (SLT). Large multiple-passenger vehicles, which carry 10 to 100 people including standees, run back and forth between several stations along a single path (shuttle), or along a closed path between the stations (loop). There are usually no extensive side spurs or branchlines requiring switching. Guideways are typically short, and headways (times between vehicles) are relatively long, up to a minute or more. The first deployments of these systems either served a circulation function at airports or activity centers or shuttled between a number of proximate activity centers (shopping complexes, amusement parks, and the like). The monorails found at some amusement parks are typical of this application.

At the next level of complexity are Group Rapid Transit (GRT) systems, which use medium-size vehicles to carry groups of 12 to 70 people. GRT systems generally have more extensive networks than SLT systems. Since a switching capability is added, GRT system networks have some branches and spurs for off-line loading, which shortens enroute delays. Because of slow switching, monorails are unlikely to be used in these applications. Headways on operating systems can range from 15 to 60 seconds. Typical applications of this technology are the system operating at West Virginia University in Morgantown, West Virginia, and the AIRTRANS system serving the Dallas-Fort Worth Airport.(68)

Personal Rapid Transit (PRT) systems could represent the third level of sophistication, which is not yet fully developed. The added technical sophistication of PRT systems includes more complex and extensive networks, smaller vehicles, and more complex control systems than GRT. PRT, in its evolved state, might consist of small 2–6 passenger-carrying cars operating on an exclusive guideway under computer control. The guideway could be either elevated or placed at grade level; it might even be integrated into some major buildings.

PRT service is personally tailored to the needs of each passenger. A passenger would first specify the trip's origin and destination, probably using a push button console to enter the information into the control system. This action automatically summons a car which proceeds to take the user to his destination non-stop. To keep system performance high so line capacities or individual travel times are not degraded, all boarding and disembarking would be done at off-line stations which do not obstruct the main line. Headways would be extremely short, from 0.2 to 3 seconds, to maintain reasonably high volume carrying capacity. This type of system would be applicable in an active, dense center city core.(66)



This people mover in Morgantown, West Virginia, is used to link parts of the campus of West Virginia University.

The principal costs of any of these AGT systems are their guideway construction expenses, which amount to 50-70 percent of total capital cost.

The specific role of these technologies is still a subject of intense debate, particularly because of the cost levels involved. Proponents claim that, if such systems can eventually be proven reliable, safe, and economical, they could become solutions to local circulation problems in congested downtown areas and help focus revitalization efforts in urban centers. Opponents claim that the costs are excessive and that other options could provide equivalent service for much less money.

The maximum design capacity of proposed-downtown circulation systems ranges from 5,000 to 10,000 passengers per lane per hour. The larger passenger capacities can be accommodated by using trains of two or more vehicles coupled together.

Dual Mode Transit

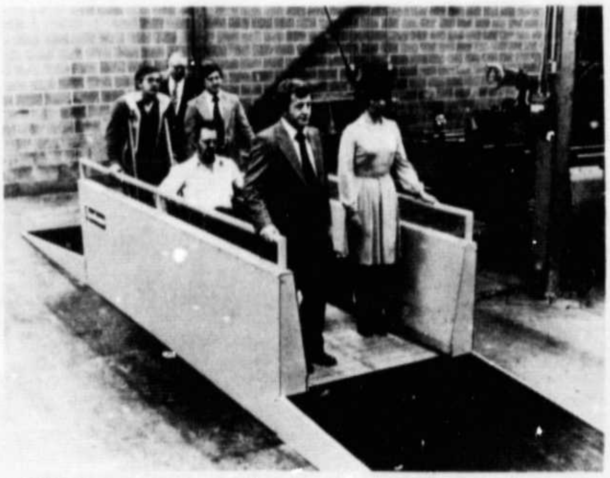
As conceived in system studies, dual-mode vehicles would run under operator control on conventional highways and then switch onto railroad tracks or a special guideway for operation under computer control. At least four approaches to the concept have been proposed:

- *The Interactive Road-Vehicle System*, where today's traffic control devices would evolve on some urban roads to the point where they not only pass information to the driver, but where they also actually control the vehicles themselves. Automobiles would have to be equipped with special sensors, receivers, brakes, steering, and engine controls to operate on such road segments. Such a system would evolve over a period of years, as highways were equipped with required control equipment and vehicles with the necessary subsystems entered the fleet.(67)
- *The Pallet System*, where conventional automotive vehicles would be driven onto flatcar-like pallets, each with its own propulsion system and controls that are tied directly to a special system guideway. After the car was fastened on the pallet, it would move off under system control to its destination. Such a system could be used by practically any car, but capacity limitations and time delays associated with loading and unloading compromise its benefits somewhat.(76)
- *The Dual-Mode Bus System* is functionally identical to a dial-a-ride or demand-responsive system, except that a dual-mode bus mounts a limited-access, high-speed guideway for the line-haul portion of its trip, gaining a time advantage. This also allows the vehicle to draw power from the guideways and increases the capacity of the line-haul segment. However, it does assume that some clustering of user destinations occurs in the final distribution portion of the trip for riders on any particular bus.(76)
- *The Small Personal Vehicle (SPV) System* is one in which small, electrically powered cars are rented by users of the system. Such a system would behave much like a computer-controlled highway but would simplify some of the parking and vehicle management problems in dense areas. Instead of leaving the small car parked, it would be returned to the system for rental by another user.(76)

Although dual mode may eventually be a promising technology, there are no concerted efforts to develop or deploy such systems at present. There have been some limited tests of the "rail-bus" approach, which is a dual mode bus concept operating on existing railroad tracks.

Systems for Small Activity Centers

Two options are currently being explored to serve circulation functions in small activity centers. Automatic Mixed Traffic Vehicles might serve a circulation function in small activity centers such as shopping malls, major tourist attractions, and central business districts, where convenient, quick, short distance travel is needed. The system consists of small vehicles which can mix with pedestrian flow. Concept studies describe small, lightweight vehicles using wire-follower guidance control and sophisticated sensors to permit operation at 1.2 to 3 mph in pedestrian areas. Higher speeds may be possible in a semi-protected right-of-way.



This is a prototype of a moving walkway system, intended to move large numbers of travelers over short distances.

The second promising option, Accelerating Walkways, are novel pedestrian-assist devices capable of transporting large numbers of travelers over short distances. A typical accelerating walkway moves at something less than normal walking speed for boarding and unloading, but it increases to more than twice the normal walking speed for the main portion of the trip. Accelerating walkways can provide service within and near activity centers such as transit terminals. Such systems might improve ridership on subways and commuter rail lines through provision of improved access, shorter trip times, and reduced congestion. Accelerating walkways are expected to compare favorably with vehicular travel in both cost and travel time. Several prototype walkway systems have been developed, but none yet provides service to the public.

Air-Cushion Vehicles

Cities located on rivers or lakes may consider hovercraft—typically, water-based vehicles that ride on an air cushion—as options. The concept of using waterways for mass transportation is not novel. Hovercraft are currently used for commuting and tourist purposes in more than 23 countries around the world. Cities, faced with daily traffic congestion on land arterials and demands for more expensive highways and bridges, might find the idea of water-borne "express buses" a welcome alternative to consider where economically feasible.

With the use of modern, high-speed vehicles, including a new breed of surface effect ships that have rigid sidewalls, trip times on water can compete favorably with auto trip times, particularly during peak periods. These craft can cruise at about three times the speed of an ordinary boat. Also, it may be possible to serve areas which are not easily accessible by land transit. Areas needing future examination include consumer acceptance, reliability, user response to changing fares, and craft design improvements.(88)

Intraurban Air Systems

Over the past decade, rotorcraft have come to play a significant—if still small—role in meeting specialized transportation needs integral to several U.S. urban centers. The primary uses are as emergency vehicles (ambulance and rescue) and for arterial traffic control. In a few areas, police are using them for pursuit of suspects. In relieving the general-purpose surface arteries of high-speed priority-vehicle interruptions, they contribute to safety and traffic flow predictability on those arteries. Expected advances in generally available rotorcraft technology, in the direction of greater operating efficiency, lower noise emissions, and heavier lift capabilities could make even further contributions: in removal of inoperable vehicles or other obstructions from traffic-clogged streets, and in providing alternative transport for unusual, congestion-creating cargo (large construction cranes, for example).

Rotorcraft and, to a lesser extent, small fixed wing aircraft have begun to serve as executive taxis and tour vehicles. It may be decades before these airborne vehicles reach the efficiency levels required for mass transit or widespread private use. Nevertheless, increasing numbers of local travelers can be expected to make use of these vehicles for high priority trips in which the time: cost ratios favor shorter transit times, even at relatively higher dollar costs. It is conceivable that, for a limited number of commuters, these aircraft could extend the feasible home to work commuting distances up to a range of 100 miles or more by the end of the century; thereby extending the effective outer boundaries of urban areas, and further increasing intercity economic and social interdependence—especially among major urban areas and their smaller neighboring cities.

SYSTEM INTEGRATION

Despite the options available to meet urban transportation needs in the future, no single option has the flexibility to perform well under the full range of demands and capacity requirements which characterize urban transportation. At least three types of trips have to be served:

- *Circulation traffic*—the movement of large numbers of people relatively short distances (less than one mile) in and around major activity centers.
- *Line-haul traffic*—moving large numbers of people longer distances (five to ten miles) on a regional basis.
- *Collection/distribution traffic*—moving people to access line-haul modes, or getting them a short distance to their destination after a line-haul trip.

In addition, growth in suburban and rural areas has led to development of low-density, longer distance traffic. This typically requires movement of small numbers of people over longer distances (5 to 10 miles) between specific locations throughout an extensive region. This type of trip is prominent in contemporary patterns of urban development and is not necessarily well served by modes which separate line-haul and collection/distribution traffic.

With the possible exception of an operational dual-mode concept, no system can serve all types of movement at all demand levels. Autos work very well at lower travel densities, but they require too much space for movement and parking to be effective for circulation or collection/distribution at activity centers. Rapid rail and other fixed guideway systems function well at high demand levels, but they cost too much to install or operate as travel density drops.(83)

The result is a need for an urban transportation system which consists of a mixture of options operating cooperatively, with service tailored to the area or clients being served. The issue is not necessarily diverting people from automobiles entirely, but rather supplying a better public option for elements of the urban trip for which the car is poorly suited. Transfers between elements of the system need to be acceptable to users, information on routes and schedules has to be available, and the reliability of the various system elements has to be assured.(87)

Multi-element bus and paratransit systems have already operated in cities such as Rochester, New York, and Ann Arbor, Michigan. Transit-center based services, where several buses loop through different neighborhoods and rendezvous periodically at a central point, are currently running in several places. The hub of the network can be a major retail facility or shopping center or a line-haul transportation terminal. This concept is also referred to as timed transfer bus service.(91,92)

Future systems may tie in fixed guideway modes to serve high density corridors, and possibly people movers or other circulation options to serve dense areas. Such a strategy can provide coverage of entire urban areas. There is some evidence that in medium-size cities, where the ratio of suburban area to downtown is not great, money lost in low-density suburban and feeder operations can be made up by profits from more heavily travelled routes in corridors or downtown.(66)

In the mid-1970s, the concept of transportation system management (TSM) emerged. Under this approach, transportation planners try to make the best use of existing highway facilities by encouraging carpooling and vanpooling, giving priority services to buses and carpools, and facilitating use of transit wherever possible. A wide variety of operating, service, and regulatory changes, in addition to minor physical improvements, can be used to accomplish this, depending on local goals and desires.

The success of a TSM strategy depends on packaging mutually supportive transportation policies and actions to complement each other. For example, a bus and carpool priority lane can be either installed in a heavily travelled corridor or simply reserved during peak use periods. This "preferential lane" can be supported by constructing fringe parking lots, improving local arterials, promoting carpool matching and transit services, and implementing other policies that favor ridesharing and transit. An element of such a strategy might be the creation of an "Auto Restricted Zone" or ARZ, in the downtown area, where cars are banned and only pedestrians and transit vehicles are allowed. Such zones can reduce congestion, improve the quality of the urban environment, reduce local noise and pollution, and stimulate some types of trade or economic activity.(43). Ridesharing provides another especially high-payoff approach to making good use of existing highway capacity.

Busways and preferential lanes are an important component of transportation systems management (TSM) strategies.

A notably effective measure to encourage ridesharing and transit usage is the establishment of a formal brokerage program. Such an arrangement helps form carpools by finding potential riders, assisting in the purchase of vans for pooling purposes, and helping potential transit riders to get schedule information. One of the first large operations, still running in Knoxville, Tennessee, uses a minicomputer for carpool matching and transit information.

Chapter 3
Small City and Urban Passenger Transportation

The passenger transportation problems of rural areas in the United States revolve primarily around transporting the disadvantaged—those young, old, poor, handicapped, or unemployed residents who either do not have access to cars or who cannot make full use of the cars they own. As such, rural and small city transportation systems are heavily involved with the social service aspects of providing accessibility. This chapter discusses the developing scope of this problem in the U.S. and explores how some "urban" options have been adapted to deal with the problem.

DIMENSIONS OF THE PROBLEM

From 1920 to 1970, the U.S. rural population essentially remained constant. However, total U.S. population doubled, with almost all of this growth occurring in urban areas. As values changed, younger people and the more affluent residents left the rural areas and migrated to urban regions. In effect, the low-density areas were being left to the aging and the poor.(52)

Fully 40 percent of America's population lived in non-urbanized areas in 1970. Since then, basic reversals of the rural outmigration pattern have taken place, and rural areas are growing again. Although this speaks well for the long-term viability of small cities and rural areas, the problems associated with having large numbers of poor and elderly will remain with them for some time to come.

As with most portions of the country, the private automobile has been the dominant source of rural mobility in recent years. In 1973, some 80 percent of rural households in the United States owned at least one automobile. However, if the car breaks down, or costs rise too high to operate it frequently, or the driver lacks the physical ability to safely control a car, the owner of the vehicle is effectively stranded. Although others may be able to drive cars for them, or they can "hitch" a ride with neighbors on a paid or unpaid basis, these approaches are typically of limited effectiveness.

In most rural areas, public transportation and intercity bus systems do not fill the gap associated with not having a car available. Conventional taxi service can be prohibitively expensive if used for all travel requirements; air, rail, and water transportation are not widely available in all low density areas. Residents without autos are thus often unable to get to work, as well as to health care and other essential services. Where it exists, the need is to provide an alternative option for mobility in low density areas, which lessens the dependency on the private auto.(71)

There are basic policy questions regarding whether the public sector must meet this need. Some say that public agencies should not have to provide public transportation to rural society. They assert that if transportation is too costly, the individual could move to an urban community, locate near a health center, or make other arrangements. Others feel that society should make provisions to support the needs of these people as part of broad-based strategies to assure community viability. Ultimately, these questions have to be resolved by state and local officials based on local conditions, resources, and attitudes.

LOCAL SYSTEM OPTIONS

The problem of serving rural areas with transit is similar to, but more complicated than, that of serving the suburban areas of large cities. Rural transit systems must be able to operate economically in sparsely populated areas and tailor their services to the requirements and limitations of each individual user. Paratransit variants, coordination with private for-profit and social service transportation providers, and ridesharing schemes seem to offer the most promise of meeting rural needs:

- *Fixed-route minibuses* can run on defined routes once or twice a week. Riders can board at widely separated stops, or arrangements may be developed to "wave down" the bus along the route. The latter approach has been used by the Links system near Greenfield, Massachusetts.(68)
- *Demand-responsive buses* can be adapted for low-density service by requiring that users request service further in advance (one to two days lead time) than in suburban operations.

This enables "tours" to be manually developed for the vehicles, without requiring sophisticated computer equipment. Use of radio dispatching allows demand-responsive service on a shorter turnaround basis, such as that provided by the Progress for People Human Resource Agency in Tennessee.(42,48)

- *Existing urban systems* can be extended into surrounding rural areas on a limited basis. For example, the Honolulu, Hawaii, city transit system extended its coverage to provide mobility to some of the rural areas of the island of Oahu. However, the economics of such an approach need close examination before a decision is made to proceed.(71)
- *Ride-sharing and brokerage systems* can be developed to pool available transportation resources. These systems can include forming bus- or vanpools where the vehicles are owned by a public agency or a major employer, or owners of existing vans are subsidized. Despite some problems with liability or obtaining insurance for some employer-owned vanpools, such systems have become especially popular. For example, Knoxville, Tennessee, has developed a commuter vanpool system which reaches far into surrounding areas.
- *School buses* can provide emergency and public transportation during off-duty hours. There are some regulatory barriers to this approach, and the narrow aisles and small seats on the bus may be a problem for some mobility-limited people. The role of school buses in reacting to contingencies or emergency situations, rather than providing regular service, has therefore been highlighted.(18)

Because of the cost of running such services, mechanisms have been proposed to provide cars to rural residents. One example was the West Virginia Community Action Agency, which provided cars to individuals who were then made responsible for transporting other users in the community. Proponents claim this approach is cheaper than providing transit in the long term. Full-scale rural transit systems may use any or all of these approaches to some degree.(71)

In addition, an alternative approach called user-side subsidy has been tried in some places. Under user-side subsidy, the monies which might have been used by a public body to cover an operator's losses are passed on directly to disadvantaged consumers. These users then spend the transportation funds to purchase service at the going (unsubsidized) rate.

The Area Transportation Authority of North Central Pennsylvania serves citizens of six rural counties of the state.

Whatever the approach chosen, private sector common carriers and taxi operators can also help provide rural mobility. Group riding in taxicabs looks especially promising in small communities.(21) Taxi companies can provide public services under "purchase of service" agreements to selected special users.(94) Intercity buses will be especially important in meeting needs for longer-distance or interstate trips.

SERVICE COORDINATION

Because of the extremely low densities involved, fares alone will probably not financially support rural systems, and subsidy from some source will be required. Since many of the services provide elderly or handicapped residents access to social service programs, such programs frequently have transportation components which can pick up part of the costs. Service coordination is one key to the viability of future rural public transportation systems: serving the requirements of the general public and the clients of a number of social service programs, and picking up some support from each group of users. Some systems have also been supported by locally imposed taxes. Steps to promote voluntarism and private sector involvement, along with more commuter-oriented service, also appear productive.

The service coordination approach to funding and operating a rural system is complex, for Federal social service grant programs in the United States typically have their own specific client group, eligibility requirements, bookkeeping and documentation standards, and local fund matching requirements. These requirements are then complicated by "billing and accounting" practices which are unique to each state. In systems which have made the approach work, one dynamic person usually takes the responsibility for making the various pieces fit together. As a result, management training for system operators may be one of the most important ways to insure that future rural transportation needs are addressed effectively.(71)

Some discussions have explored the role of computers in trying to solve the paperwork problems of rural transit systems. The advent of home computers, plus standard routines which can be used to develop reports required by state or Federal sponsors, may make the use of multiple funding sources far more attractive.

There is also a six-state initiative, called the Transportation Accounting Consortium, which intends to simplify reporting requirements. It emphasizes use of a "standard chart of accounts" to make records from various systems comparable. The state of Iowa, for example, has developed a Uniform Data Management System (UDMS) to facilitate record-keeping and reporting on bus operations which may be used as a model by other states involved in the project.(10) The combination of such administrative simplification and cheap, readily-available microcomputers may ultimately hold the solution of the coordination dilemma.

Chapter 4
The Private Automobile

The impact of the private automobile on life styles around the world would have been practically unthinkable at the time the first "horseless carriages" were introduced. Many cities were maturing as the auto came on the scene, and the spatial structure of many of these urban centers became predicated on having the auto or any auto-like system for mobility. This section will examine the role of the private automobile and speculate on its technological future, with particular emphasis on safety and energy needs.

DOMINANCE OF TRANSPORTATION

The dominant element of passenger transportation in the future will probably be a descendent of today's private automobile, and for good reason. The car provides a combination of personal service and schedule flexibility at an "acceptable" cost no other mode can match. The key reasons for this dominance include relatively low cost, high reliability, instant accessibility, fast travel time, and ability to haul packages.

The private car is currently used for some 90 percent of all passenger transportation in the United States. Even if a major energy shortage forced people to select common carrier modes for a large number of their trips, the dominance of the automobile would probably continue. For example, even if ridership on all other common carrier modes doubled, the automobile would still account for some 80 percent of all trips.(2)

In many cases, the automobile is the only reasonable option, and for trips up to 500 miles, the auto has had no effective competition. The coverage of the U.S. highway net means that the private car has been able to reach some places which no other mode of transportation can. However, recent developments (especially energy concerns) may result in a switch in shorter trips (200–500 miles) from the auto to buses, rail, and commuter aircraft. These developments may be especially important in light of the rural and small city development trends noted earlier. Only for long distance trips has auto patronage previously been challenged by the common carrier air services.

Human psychology may be among the reasons for this dominance of the private auto. The driver of a car has a great deal of power under his or her control and is in effect "master of his or her own destiny" for the duration of the trip. This personal autonomy may serve as a balance against many of the depersonalizing, dehumanizing trends in a large highly organized society. The car has also evolved into a status symbol in many societies. Common carrier modes may attempt to improve their amenities and to replicate the car's service characteristics, but they may find it hard to match some of these subtler roles the car plays in modern culture.

LIMITS ON APPLICABILITY

Unfortunately, the popularity of the private automobile has created some adverse side effects which reduce the benefits in transportation roles. Among the most emotionally charged are occupant and pedestrian safety problems. Traffic accidents are currently the sixth leading cause of death in the U.S. Among citizens under age 45, traffic accidents are the leading cause of death. Deaths from auto accidents rose above 51,000 in 1979, and injuries number some 4 million per year. Overall, the annual cost of traffic accidents was estimated to be above $50 billion.

In addition, the auto requires a great deal of space for operation, storage, and parking. These characteristics make it unattractive as a mode of transportation in central cities. When people bring cars into the city or other activity centers on work or shopping trips, there are few problems at the low-density end of the trip. However, as traffic builds up, the various arterials congest, more parking space is needed, and more support facilities must be installed. There may be "better," or at least more profitable, uses of available land in urban centers than for parking.(96) Eventually no more space is available, with the result that some downtown areas have more or less continuous congestion all day. The car helped create this urban growth pattern and is helping to perpetuate it.

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The automobile has also been a major contributor to air pollution problems in large cities. Regulatory approaches on a city-wide scale have to date been unworkable in the U.S., simply because no really acceptable transportation alternative to the car exists for the general public. Just as autos dominate transportation in general, they dominate urban transportation. Doubling or tripling the availability of public transit, even if it were possible to attain an acceptable level of ridership, would have a limited impact on total automobile usage. To significantly decrease dependence on the auto would require major investments in new transit facilities, and the effect would probably be only to slow, rather than to stop, the growth of auto traffic in urban areas.

The automobile currently is the largest single consumer of petroleum, using about 52 percent of the petroleum consumed for transportation in 1979 Since the late 1950s, it has been necessary for the U.S. to import oil from a wide variety of foreign sources, and in 1979 over 45 percent of the petroleum used in the U.S. was imported. The potential for interruption of supply and the outflow of money (dollars) from the U.S. (or any) economy has raised some concerns in some quarters. In addition, competition for existing petroleum resources will increase in the latter part of this century, possibly resulting in higher prices for the available supply.

Changes to improve the fuel efficiency of passenger automobiles and light trucks have affected all vehicle components and systems. These changes have required replacement of nearly all of the tooling and equipment needed to manufacture components of the vehicles. This retooling extends far beyond that necessary for normal styling and model changes, and manufacturers and suppliers have had to spend large sums for new equipment.

THE DESIGN PROBLEM

Traditionally, the consumer has been able to choose from a wide variety of car types and models. Sizes ranged from small "subcompacts" to full-size "luxury cars." Design choices made in the evolution of these vehicles frequently have broader impacts than the way the car looks or runs. A Federal *Interagency Study of Motor Vehicle Goals (MVG)* beyond 1980 singled out several areas of impact of passenger car design choices:

- Total Fuel Use
- Deaths and Injuries
- Air Quality and Health
- National Resource Availability
- Automotive Industry Impacts
- Consumer Costs
- Broader Impacts on the National Economy (89)

These general areas are interrelated, since a decision to improve automotive performance in one area may lead to compromises in other aspects of performance. Auto designers now recognize the environment in which the car will operate and make tradeoffs between the various elements and features of the car to achieve desired goals. The motor vehicle goals study selected automotive fuel economy as a major goal in the design process and assessed its impacts on other attributes:

- Size (Roominess)
- Performance (Acceleration and Gradeability)
- Auto-Structure Technology
- Engine Technology
- Drivetrain Technology
- Emission Control Technology
- Emission Standards
- Safety Requirements

Examples of the types of vehicles that result from these tradeoffs can be found in the National Highway Traffic Safety Administration's Research Safety Vehicle (RSV) program. The RSV program focused on developing and testing cars which weigh less than 3,000 pounds, achieve fuel economy in excess of 30 miles per gallon, and provide occupant protection in a head-on collision at 40 miles per hour. The Calspan Corporation of Buffalo, New York, and Minicars, Inc., of Goleta, California, were selected to build prototype RSVs. The Calspan vehicle design involves integrating current design advances for an operative weight of 2,700 pounds. The Minicars' vehicle design uses lightweight materials and structural innovations in its approach, resulting in an automobile weighing 2,320 pounds.

Features under test in the RSV prototypes include a reinforced structure, run-flat-tires, electronic instrument displays, foam-filled body structure members, damage-resisting bodies, anti-skid brakes, and radar-actuated brakes. The Minicars' vehicle with a stratified charge engine, should have a fuel economy of some 34 miles per gallon. Through the integration of advanced technology engines and transmissions with light-weight vehicles, fuel economy levels of 50 to 60 miles per gallon appear feasible.

FUEL ECONOMY AND ENGINE TECHNOLOGY

In the short-term, changes in driving habits of the general motoring public, industrial auto fleet operators, and truck and bus operators can help improve fuel economy. Techniques include better trip planning, proper vehicle selection, good maintenance habits, and fuel-saving driving techniques.

Congressionally mandated fuel economy standards call for manufacturers to reach a level of 27.5 miles per gallon overall by 1985, and the auto industry will probably meet and surpass this goal. In the 1980–1990 period, the principal gains in fuel efficiency from engine technology will be made through the improvement of the spark ignition engine and the introduction of diesels in larger numbers. Engine performance will be improved through control of spark timing, the fuel/air ratio in the engine, exhaust gas recirculation, valve operation, and combustion chamber design. The reduction in engine size and weight, plus the addition of turbocharging and supercharging, have also improved the efficiency of spark ignition engines.

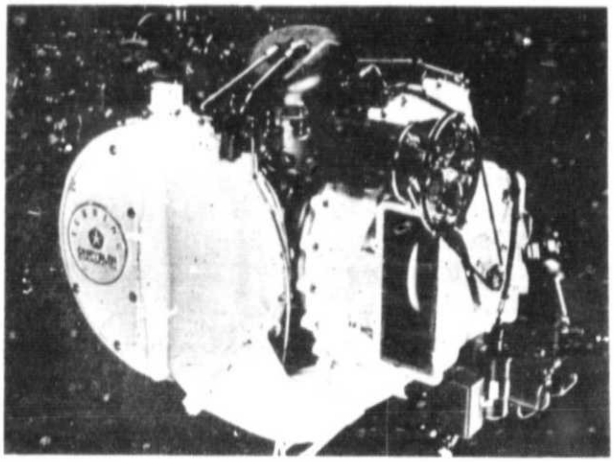
In addition, "lean" combustion systems and some kinds of rotary engines show promise for improved fuel efficiency. Indirect injection diesel engines show about 25 percent improvement in fuel efficiency over current gasoline engines, and direct injection diesel engines are even more efficient by about 10 percent. The emissions from diesel engines are generally low. However, to meet future statutory levels of nitrogen oxides and particulate emissions, aftertreatment devices will probably be required for diesel engines. Recent information indicates that these emission control problems will be solved.

For the longer term, research is underway on other advanced technology engines. Engines based on Stirling (expansion and compression of sealed working fluid) or Brayton (gas turbine) power cycles have the potential for low emissions and fuel economy. However, vehicles using these powerplants are unlikely to be in production before the early 1990s.

Another mid-term and long-term alternative is the electric or hybrid vehicle. As costs of petroleum-based fuels increase, electric and hybrid vehicles are being considered as a cost-effective alternative for a number of transportation

This Research Safety Vehicle was built under contract to DOT's National Traffic Safety Administration.

missions. In the near future, some commercial vans and light trucks could be replaced by vehicles with battery-powered propulsion systems. In the passenger car sector, General Motors has announced that it will offer an electric two-passenger runabout in model year 1985.



Automobile gas turbines could run on a variety of fuels.

Significant progress in battery, motor, controller, and propulsion system development is being achieved in cost-shared government/industry research and development. Estimates of the number of these vehicles that could begin service by the end of the century vary widely. Actual market penetration will depend upon economics, vehicle performance relative to conventional vehicles, the energy situation, and similar factors.

There has also been increased interest in alternative vehicle fuels. Discussions have focused on propane, methane, alcohols, natural gas, and even (in the longer term) liquid hydrogen. With the exception of gasoline/alcohol mixtures (gasohol), there has been limited experience with these options. Some experimentation is ongoing with commercial or governmental vehicle fleets.

SAFETY

The future of private and commercial vehicle transportation will raise a number of safety issues. First, since fuel-efficient small cars offer less protection in crashes than larger cars, occupant deaths and injuries may increase unless some protective action is taken by passengers or manufacturers. Since commercial heavy vehicles are increasingly involved in accidents, better education for drivers and improved operational practices may be necessary. To gain the safety and fuel efficiency benefits, it may be necessary for police to step up enforcement of speed limits. Accident severity increases with speed; the kinetic energy (energy of motion) that must be dissipated in any crash rises in relation to the square of the vehicle's speed. Effective programs can also be undertaken at the State level to curb drinking drivers.

Young drivers (ages 16–24) are heavily represented in accidents. As a result, state programs in education, licensing, alcohol safety, and traffic enforcement may have an especially high payoff with new drivers. New problems such as moped accidents and motorcycle helmet usage might also be addressed with this group.

Both technological and behavioral approaches to the problem of highway safety are possible. Numerous changes in the highway system and in auto vehicles have contributed substantially to highway safety.

- *The Interstate Highway System*—which has saved an estimated 5,000 lives each year.
- *Lap belts and shoulder harnesses*—which have already saved thousands of lives each year, even with partial usage.
- *Improved highway design and technology* including flatter grades and curves, longer speed change lanes, anti-skid surfaces, paved shoulders, and increased sight distance.
- *Traffic control designs*, including better centerlines, delineation posts, direction and other signs, flashing beacons, curve warning signs, wider lanes, and stabilized shoulders.
- *Improved design of car interiors*, including padding, energy absorbing steering wheels, breakaway knobs, head restraints, and improved windshields.
- *Improved vehicle technology*, including automatic transmissions, power brakes, tires, vehicle lighting systems, and power steering.

As a result of these various improvements, highway fatalities today remain below the 1965 level, despite a more than 50 percent increase in vehicle registration and travel. However, more than 50,000 fatalities and hundreds of thousands of serious injuries still occur on our highways each year.

Programs are in place or are being developed to make further improvements in the safety of the roads. The auto industry is working to improve motor vehicle occupant crash protection for vehi-

cle occupants, and States are working to improve enforcement of speed limits, to encourage more stringent and successful alcohol control, and to increase the proportion of highways that conform to modern standards for highway safety.

The current estimate is that 9,000 fewer lives would be lost each year if seat-belt usage reached a 60–70 percent level. However, a recent survey shows that in-traffic belt usage is now at 10.9 percent. In the 20 countries that have adopted laws requiring the use of safety belts and that have effective public information and enforcement programs, motor vehicle fatalities and injuries have been reduced. Nevertheless, the fact that no State in the U.S. has yet adopted such a law—despite attempts to do so in several States—indicates that the political practicality of such an approach in this country is questionable. However, several states currently require child restraint use for children under 4 years of age.

One practical alternative to seat belts might be to protect vehicle occupants with automatic or "passive" restraint systems. These passive restraint systems require no action to "buckle-up" as a precondition for protection in a frontal crash.

Two types of automatic occupant restraints have emerged from safety research programs. These are the air bag and the automatic seat belt. The air bag system uses an inflatable bag contained in the dashboard and steering wheel of a vehicle, an inflating cartridge, and a sensor system. When the sensors, typically located in the front vehicle structure or engine compartment fire wall, detect a deceleration typical of an accident, they trigger inflation of the bags, which then cushion the occupant from severe impact with the vehicle interior.

Another type of passive restraint is the automatic seat belt. Automatic belts have been sold as an option on Volkswagen Rabbits since 1975 and in General Motors Chevettes since mid-1978. These belts move into place when a person enters the front seat and closes the door. The designs incorporate an emergency locking retractor which allows the occupant to move freely under normal conditions, but automatically locks the belt webbing to restrain occupants when a crash impact occurs.

Other automotive safety problems are associated with drinking drivers and drug users. Strict enforcement of traffic laws and improved public information programs to increase public awareness of the likelihood of being caught may be the most effective long-term way of controlling this problem. Effective court treatment of offenders and rehabilitation programs can play a significant role as well.

Improved technology also has had some effect in this area. Video tapes of intoxicated drivers and chemical breath testers are used as evidence to get convictions. Devices that lock an auto's ignition system and that require more physical coordination to turn off than a drunk driver has are also effective. In addition, beneficial effects may be obtained from other devices now in the development cycle, such as a "drunk-driver warning system" designed to reduce the incidence of drunk driving by individuals previously convicted of driving while intoxicated.

The interstate highway system's improved design and technology has played a major role in saving thousands of lives each year.

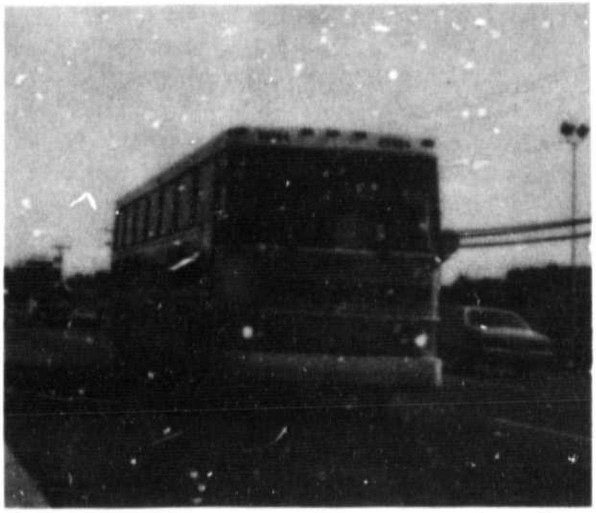
IMPACT OF ELECTRONICS

Use of sensors and electronics have already made great impacts on traffic control. Automated systems can detect changes in flow rates on major roads and can signal timing patterns to keep traffic moving smoothly. A good example of such a system is ramp metering equipment. Such systems track the traffic densities on congested freeways and only allow other cars to join this flow at a limited rate calculated to keep traffic moving. Radio or sign message systems to inform motorists about developing traffic congestion or alternative routes are also gaining wider use. The profileration of citizen's band (CB) radio also serves this function to some degree, and there have even been discussions of requiring CBs in all cars in the future.

Computer applications are being rapidly implemented in private autos. The development of microprocessors is one technical breakthrough which makes possible computer application in cars on a scale which would have been impractical with conventional computer technology. Microprocessors are being used in the latest model automobiles to provide control of various engine functions and thereby to improve fuel economy without worsening the vehicle's emissions. In particular, the interactive road vehicle system for urban applications, described earlier, may also evolve on an intercity basis. Automated highways have been discussed for years, but technical advances now seem to make the concept more economically feasible.(67)

There are also ongoing attempts to make existing and proposed navigation systems more applicable to a wide variety of users. An example is the U.S. Coast Guard LORAN-C (Long Range Navigation) system, a radio navigation system that has been used at sea. Several land-based applications of the system now being investigated include automatic monitoring of police or transit vehicle positions, highway accident location, automatic vehicle location or dispatch, and highway inventories. Major improvements in productivity associated with the application of the technology appear probable. The proposed satellite-based NAVSTAR Global Positioning System can be applied in a similar manner.

Chapter 5
Intercity Passenger Transportation



Intercity bus systems are an important service to low density areas, especially those not serviced by rail systems.

With some indications that national population shifts are occurring, intercity passenger travel may assume an added importance. Traditionally, the private automobile and common carrier aircraft have served the bulk of the intercity travel market, with cars making most of the short trips and aircraft making a good proportion of the longer ones. In particular, air travel accounts for over half the person trips over 1,000 miles in length.

Intercity transportation will be affected not only by national population shifts but by the changing structure of the national and international economy, the cost of energy, and imponderables such as personal values and attitudes toward environmental conditions. For instance, will the time saving objective continue to drive the development of ever faster modes of transportation with a consequent shift toward those modes that can accommodate the speed requirements? Will we reach a point in our perception of the quality of life where time saving becomes a less important variable, and where factors such as travel comfort, safety, convenience of access to terminals, and on-board amenities become determining elements in the development of new transportation facilities and services? Only the users of intercity systems themselves can decide.

Some of the possible future prospects for the various intercity transportation modes will be discussed in this section.

INTERCITY BUS SYSTEMS

Because of the coverage of the national highway network, intercity bus systems have the potential to extend service to a wide variety of locations. Typical bus speeds, terminal to terminal, have been similar to the automobile, assuming nonstop service. In markets where travel demand cannot economically justify nonstop service, operators must augment their routes with intermediate stops to supplement ridership and revenues. If these stops involve extensive waiting time, or are a substantial distance from the main route, they can degrade travel time extensively. The costs of providing bus service are generally below those for air or rail trips, especially for short distances. It should also be noted that the bus has a major image problem—bus service is considered "lower class" or "inferior," and bus stations do not have a good reputation for security.(40)

The intercity bus should remain an important mode in serving low-density areas like small towns or rural areas. As with any multiple-occupancy mode, there is some potential for energy conservation by shifting passengers from the private automobile, although a major shift would be required.

In corridor applications, some concepts have been explored which would run buses at 90–100 miles per hour on exclusive lanes either on existing highways or with new construction. However, there have been no moves yet to deploy such a system.

In corridors with existing rail service, efforts may be intensified to provide common intermodal terminal facilities and restructure bus service as a complementary feeder service the line-haul rail service. The increasing operating cost of separate bus and rail terminal facilities and the high cost of providing effective local public transit access to intercity terminals may stimulate the development of combined terminal facilities for separate intercity operators.

PASSENGER RAIL SYSTEMS

Passenger rail technologies are attractive where large volumes of people have to be moved in areas with limited available space for transportation. They are not effective in serving low passenger demand levels. As a result, passenger rail service in the U.S. virtually disappeared in the 1960s. In 1971, the National Railroad Passenger Corporation, known as Amtrak, was formed as an attempt to preserve some passenger services.

Improving rail passenger facilities is expensive. Some idea of the costs involved in upgrading lines for highspeed corridor service has been gained from the experience of the Federal Railroad Administration in implementing the Northeast Corridor Improvement Project, and from estimating the cost of other so-called emerging corridors in the midwestern, western, and southern regions of the U.S. Congress authorized an expenditure of $2.5 billion for the Northeast Corridor Project, as part of the Railroad Revitalization and Regulatory Reform Act of 1976. The goals of the mandated program call for significant trip time reductions, increased schedule reliability and station rehabilitation, as well as placing new equipment into service between Washington and Boston. Congress also required that the service be managed in such a way as to reach and sustain an operating break-even point by 1987.

Upgrading passenger vehicles to run at higher speeds on existing track may be less costly and more desirable in some instances than lessening the severity of curves and making other changes to accept high-speed passenger trains—particularly where freight and commuter trains share the right-of-way. In Great Britain, France, and West Germany, research is advancing on specially designed passenger car suspension systems that compensate for track irregularities and permit cars to "bank" in tight curves. Significant progress has been made in perfecting propulsion systems, particularly on electric traction systems, safety and track structures, centralized computer control systems, and signaling. These incremental passenger system innovations, tested and introduced into revenue service in Europe and Japan, are benefitting the U.S. rail system, as some of the technology is being transferred.

The Budd Company, the only remaining passenger car builder in the U.S., has developed a new rail diesel car the (SPV–2000) that can be used in nearly every kind of rail passenger service, including commuter, branch line, and intercity. The New York Metropolitan Transportation Authority has ordered 10 cars for use between Poughkeepsie and Croton-Harmon and between Brewster and Dover-Plains, and the State of Connecticut has purchased 12 cars for operation on Amtrak's New Haven-Hartford-Springfield line and another for the Norwalk-Danbury branch of Conrail's New Haven Division.

The Budd Company has developed the SPV-2000, a rail vehicle that can function in many different kinds of rail service.

Rail systems may become more important in some areas if major oil shortages occur, and it becomes necessary to shift corridor travel from cars or planes to other options. Since rail systems can be run electrically, be powered by coal-based synthetic fuels, or even use coal-fired steam (if it really became necessary), they have become especially useful if a tight energy scenario occurs over the long term. In the interim, the economics of rail systems are a serious concern on a national scale.

TRACKED LEVITATED VEHICLES (TLV)

In their efforts to remain competitive with the airlines, today's passenger railroads have already borrowed the gas turbine engine, aerodynamic styling, and on-board customer service from air transport technology and experience. As a next step, extensive research is being carried out in Japan and West Germany to develop trains which do not move along a track but which travel on a cushion of air or are magnetically suspended. These advanced trains are called tracked levitated vehicles, or TLVs.

At high speeds, tracks must be exceptionally smooth and accurate to prevent the wheels from developing excessive vibration. At the same time,

track wear becomes greater as speed increases. These problems can be solved if the train is lifted slightly above the track. Air resistance then remains the major factor to be overcome.

Although a number of options have been put forward, only the magnetic levitation systems have advanced to the point of testing in a limited commercial environment. The concept has been studied in the U.S. by Ford and Stanford University, in Japan by the Japanese National Airlines, and in Germany by the Siemens AEG-BBC consortium. Systems are being readied for testing in Japan and Germany.

TLVs are a longer term option for corridor markets served by highspeed rail. Because of the high per-mile cost of their guideways and the need for large-radius turning curves, the installation costs of these systems are fairly high. One 1974 analysis, probably conservative by now, placed their fixed facility costs at $7.0 million per mile outside urban areas. Since a large part of the urban costs of TLV systems are associated with tunneling, a technology breakthrough in that area might improve their attractiveness somewhat.(79) Innovative financing approaches may have to be considered if a TLV deployment is planned.

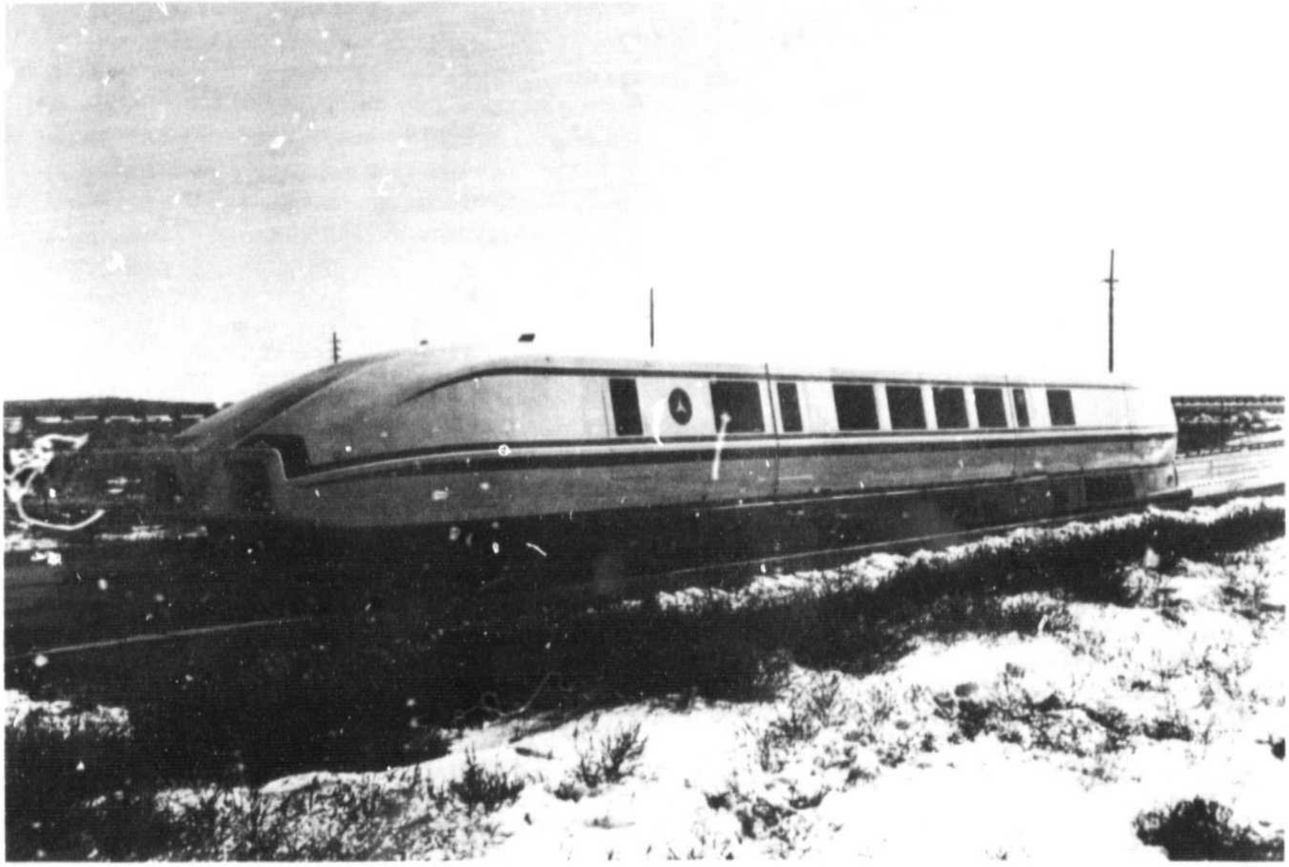
Because of costs, potential environmental impacts, and political feasibility, TLV systems are currently viewed with serious reservations in some quarters. However, current projections by the Office of the Secretary of Transportation indicate that, even with the Northeast Corridor upgrading program, the transportation system in the Boston-Washington corridor will probably reach capacity by 2,010. This date may advance, if a major diversion to rail from auto or air occurs. TLV technologies are one option for providing the additional capacity needed in this and similar applications.(63)

AIR SYSTEMS

As mentioned previously, air transportation dominates long-distance trips and is the most popular common carrier mode for trips over 200 miles. Barring any major petroleum shortage, this dominance should continue, especially because of the speeds and high level of amenity which characterize air travel. A number of paths of technical improvement might be followed:

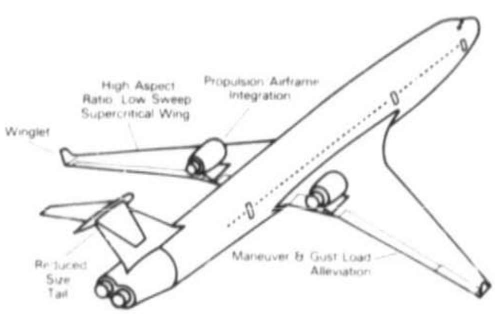
- *Advanced Technology Subsonics.*

  The next generation of commercial jets after Boeing's 767 and 757 aircraft is ex-



This Prototype Tracked Air Cushion Vehicle (PTACV) was tested at the Department of Transportation Test Center near Pueblo, Colorado.

pected to incorporate several new technologies to cut operating costs and reduce energy consumption.(41) One design approach might be to use slightly swept-back high aspect ratio (long, slender) wings and control surfaces, possibly incorporating supercritical wing profiles and active controls. Small aerodynamic improvements such as winglets may also be employed. Winglets act in the crossflow on the main wings, producing a net forward thrust and saving some 4–6 percent on fuel.(14) Composite materials, consisting of graphite or boron fibers embedded in an epoxy matrix, may be used to cut structural weight. Composites have already been used in helicopter rotor blades and in making secondary structures in commercial transports.



This diagram illustrates some features considered for advanced subsonic air transports (adapted from Ref. 35).

Improved propulsion technology can also provide modest but significant efficiency gains in the next generation of engines.(41) Advanced technology turbofan engines could could increase fuel efficiency at least 12 percent by a combination of component improvements, such as exhaust stream mixing, better clearance control at the tips of compressor and turbine rotors, low-loss seals, and refined blade shapes in fans, compressors and turbines.(30) Other gains will result from improved engine diagnostics and design for lower performance degradation during service life.

Many new jetliners will enter service in the early 1980's. Planes under development include Boeing's 737-300, 757, and 767; an improved McDonnell Douglas DC-10; Lockheed's L-1011-400; and Airbus A310 and A320.

Later introduction of advanced turboprop engines also promises reduced fuel consumption (relative to the improved turbofan). The key in turboprop technology is the achievement of high efficiency at or near the speed at which turbofan transports fly, while maintaining satisfactory levels of noise and vibration inside the passenger cabin. A new generation of advanced propeller aircraft may result.

Technological improvements in both turboprop and turbofan engines should continue to reduce the area around airports which is affected by aircraft noise, especially during landings and takeoff.

- *Short and Reduced Takeoff and Landing Aircraft.*

By using an airplane's propulsion system to augment its wing lift, adding special flaps, or making other design changes, it is possible to cut the length of runway needed for an aircraft to take off or land. This capability also reduces the airspace required in terminal operations.

NASA's Quiet Short-Haul Research Aircraft (QSRA) is shown approaching its landing strip.

Propulsive lift techniques for achieving this include internally blown flaps powered by air bled from engine turbines, externally blown flaps using engine exhaust, upper surface blowing using engine exhaust, augmentor wings using entrained air, and vectored (directed) engine thrust. Unfortunately, these changes when used to achieve very short runway capability require higher relative initial investment costs, and also increase operating costs and fuel consumption.(14)

It is therefore unlikely that short takeoff and landing (STOL) aircraft operating from

runways under 2,500 feet will enter extensive commercial use in the near future. However, short runway aircraft (SRA) systems, using 3,500 to 5,000 foot runways may become commonplace, especially if capacity increases and constraints on the availability of new large airports force major use of smaller, existing satellite airports.(38) Expansion of commuter aircraft operations to smaller communities may also provide another market for STOL and SRA vehicles.

- *Vertical Takeoff Aircraft and Helicopter Variants.*

Vertical takeoff and landing (VTOL) capability is even more costly than STOL, but it offers a potential point-to-point feature which may compensate for its expense. As with STOLs, use in downtown areas is unlikely, unless there is a change in many of the current popular attitudes about environmental impacts and safety. However, there were many breakthroughs with respect to helicopter costs during the 1960s, and helicopter variant or hybrid systems exhibit some promise in the longer term. Depending on the course of development, these systems may be useful for airport feeder service or trips in the 100–300 mile range; those which today are "too far to drive and too short to fly."(67)

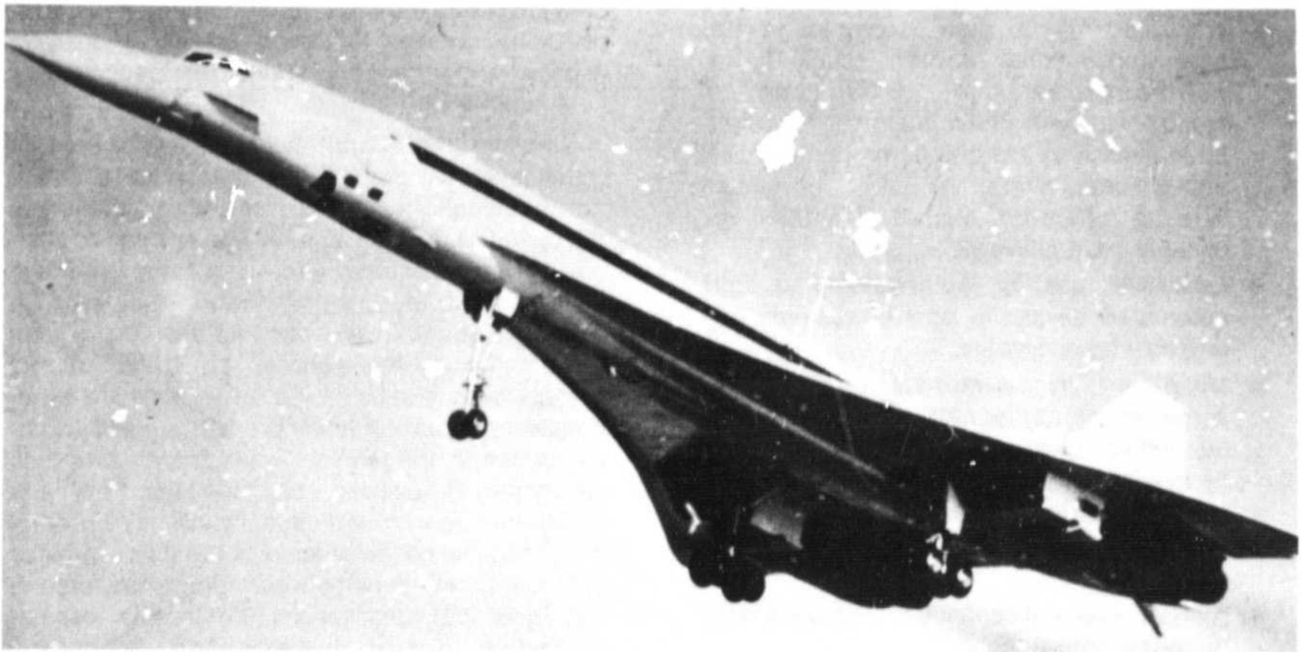
- *Supersonic Aircraft.*

Today's Concorde aircraft have direct operating costs which are triple, and total costs which are double, those of wide-body supersonic aircraft on a seat-mile basis. Their fuel usage is three times as high as a subsonic aircraft. Using the aircraft technology of the late 1970s, a second generation SST could be built whose direct and total costs would be essentially competitive with, for example, a Boeing 747, including consideration of the subsonic flight phases necessary to avoid overland sonic booms. Top speed for such planes in intercontinental service would be from 1.5 to 3 times the speed of sound (about 720 mph at sea level). FAR-36 (heavy weight) noise certification of these planes would be required and achievable, as would meeting EPA emissions standards.

- *Hypersonic Aircraft.*

There may be the possibility in the much longer term of hydrogen-fueled hypersonic transports, flying at 5-6 times the speed of sound at altitudes above 100,000 feet. Technologically, the craft requires major advances in propulsion, structures, and aerodynamics. The supersonic combustion ramjet, or scramjet, is currently the only known air-breathing engine that can operate above Mach 5 (five times the speed of sound). This engine would have to be perfected to make the concept feasible.

The costs of developing either an SST or an HST aircraft may be beyond the capability of any one manufacturer. Some type of



The Concorde was one of the first operational passenger SST's.

government assistance would, therefore, be needed if a decision were made to develop the technology. Such assistance might be in any number of forms, including enabling legislation to waive antitrust restrictions, loan guarantees, or risk limitation. Direct government support of a prototype aircraft is not an agreed upon element in an SST or HST development program.(26)

- *Lighter-Than-Air (LTA) Craft.*

  Studies have identified new uses of lighter-than-air vehicles.(20) These heavy-lift airships would not resemble dirigibles of the past. They would be hybrids that combine helicopter-type propulsion and control with buoyant hulls. Some proposals have suggested using extremely large airships for long-haul transportation of passengers or cargo, but economic studies have not revealed a significant market potential.(36,38) The principal uses would be for relatively short-range cargo and related purposes, and are discussed in 6 of this report.

To assess which of these future developments in aviation were most likely, and under what circumstances they would most probably occur, DOT's Federal Aviation Administration undertook a study of alternative aviation futures. The results, summarized in the report *Aviation Futures to the Year 2000*, set out five broad scenarios ranging from limited to expansive growth of the air system and projected the most likely system characteristics for each.(58) The study's findings include the following:

- With moderate to high economic growth, new conventional aircraft, such as a 150-passenger jet STOL or a 1,000-passenger jumbo jet transport, might be in service by the end of the century. Unconventional aircraft (VTOL's, helicopter variants, LTA craft, etc.) in air carrier applications are unlikely.
- Extensive use of semi-automated and automated air traffic control systems will probably be necessary.
- Major additions to airport capacity, including some new air carrier airports and a substantial number of general aviation airports, will be essential.
- Use of non-petroleum fuels is unlikely, but more fuel-efficient transports should be available.
- Aircraft noise will continue to be a constraint on system growth.

Petroleum shortages may force consideration of new types of fuel. Synthetic jet propellants might be made from coal. Other fuels which might be used include liquid hydrogen or methane.(13) The U.S. once had a nuclear aircraft developmental program, but it was shut down in the early 1960s because of problems in meeting military requirements and in achieving a lightweight, well-shielded reactor system. A civil aircraft with nuclear power would also have problems with environmental constraints and economic requirements. However, fuel shortages, combined with technical advances, may one day lead to reconsideration of this option.

The Airline Deregulation Act of 1978 has added impetus to the need for relieving the congestion at major hub airports. Delays to air carriers are running over $1 billion (1979) and are expected to approach $5 billion in the mid-1980s. In the near term, the short runways (5,000 feet) at independent facilities for commuter and general aviation aircraft could provide significant congestion relief. This would provide benefits to the air carriers (an estimated 85–90 percent of service) as well as the commuter/general aviation aircraft operators (an estimated 10–15 percent.) However, since delay is also a function of economics, it is difficult to be sure how accurate these and similar projections may prove to be.

The Airline Deregulation Act also provided an added spur to the growth of the commuter airlines in this country. In 1979, which was the first full year under deregulation, nearly 14 million passengers flew on commuter carriers, an increase of 27 percent over the previous year. Commuter airlines, operating smaller turboprop planes, should be especially important in providing service to smaller communities.(7)

Whatever the aircraft technology, growth in air traffic levels will probably continue. A fuel shortage could constrain this growth for a time, but there is the option of developing a new generation of alternative fuel powered aircraft as the shortage developed. Under any scenario, increases in capacity levels will necessitate major improvements in the national air traffic control system, with extensive use of automation to increase individual controller productivity and assure safety. Within the terminal areas, improvements in passenger processing, baggage handling, and within-the-airport transit capacity will be necessary to increase landside capacity, as well as to provide efficient connections betwe n major hub airports and inner city destinations.(93) In this respect, automated ground transportation information

systems are being designed as one means of expediting passenger flow from high density airports. As noted before, growing traffic levels at some hubs may lead to development of satellite or reliever airports located at some distance.

Traffic increases also require a concerted effort to control aircraft noise and reduce adverse environmental effects. As noted before, work is continuing on air transport noise reduction, which should ameliorate that problem somewhat. As newer, quieter, more fuel-efficient aircraft are introduced, the older, noisier models will be removed from service. Current Federal regulations require that, as a condition for operation in the United States, all large jetliners meet Federal noise standards by 1985. Thus, older, noisier aircraft must be modified to reduce their noise, be re-engined, or retired.

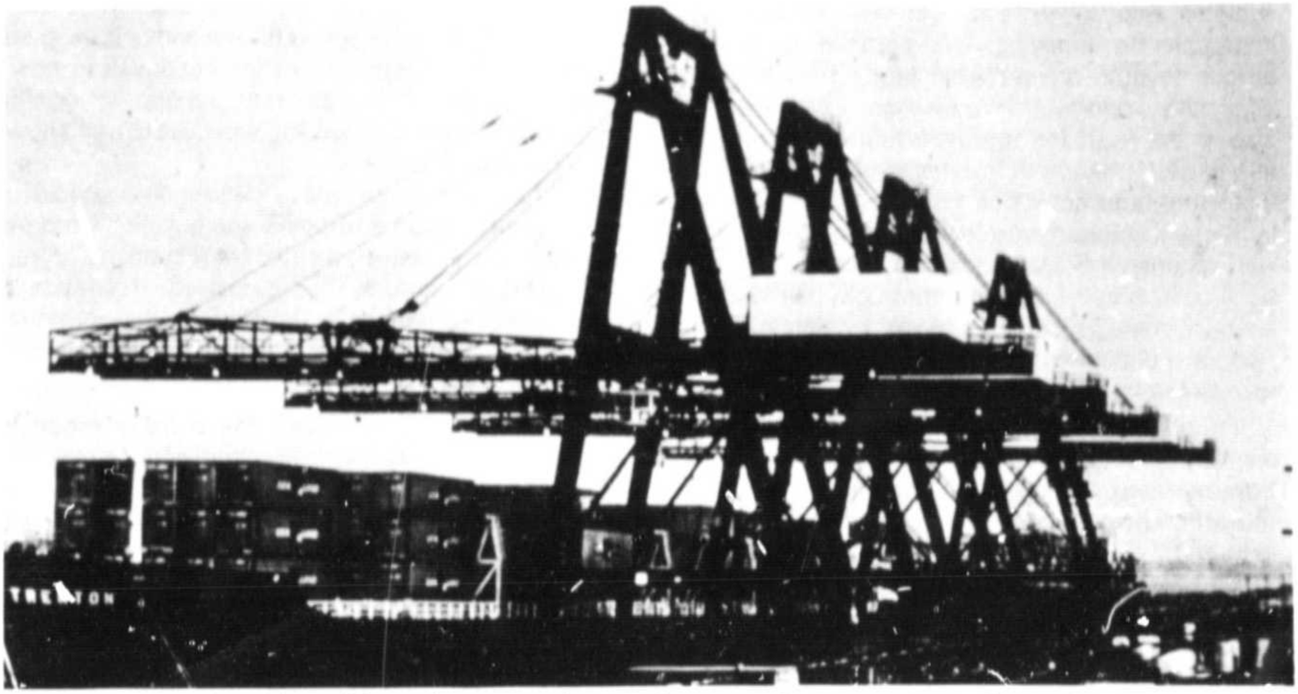
MARINE PASSENGER SYSTEMS

Passenger marine transportation has declined until recently, with much of the long-range traffic diverted to passenger airliners. However, there are some applications where new marine systems may show promise for medium distance shuttle or ferry runs. For example, hydrofoils have been successful transportation systems on a global basis. It is estimated that there are at least 900 of these craft operating in the East Bloc alone, and successful hydrofoil technology is now decades old.

Another type of craft is the wing-in-ground effect vehicle. Both large and small sizes of such craft are being investigated in the Soviet Union and West Germany. Flying close to the ocean suface, these craft would operate in a high lift to drag regime. Some configurations can operate as conventional aircraft with some loss in efficiency and speed. They are potentially highly flexible, efficient vehicles.

Surface effect ships, which amount to large ocean-going hovercraft, are another possibility. In very large sizes, these vessels become highly efficient and are excellent candidates for nuclear or hydrogen propulsion.

Chapter 6
Cargo Transportation



Container ships will be an important element of tomorrow's cargo transportation system.

This chapter discusses the possible future of freight transportation and the impact which new technology may have upon it. in some respects, cargo transportation problems are more complicated than those of passenger transportation, since people are relatively homogeneous in size and shape and can assist in making their own routing decisions. The spectrum of commodities and items shipped by freight is broad: small, valuable items such as electronic components, perishables such as fruits and vegetables, heavy manufactured products such as farm equipment, and bulk commodities such as grain, oil, and coal. Each of these types of items must be treated differently, as a result, a remarkably diverse and complex freight system has evolved worldwide.

In addition to the movement of conventional commodities, an area of growing concern is the rapid increase in hazardous materials—required by industry, agriculture and medicine—that must be safely moved. Because of the possibility of an accident, State and local governments are considering or adopting laws to protect their jurisdictions. A spectrum of response and support mechanisms is also evolving at the Federal level. In any case, this issue adds a further degree of complexity to an already intricate set of problems.(95)

MOTORCARRIERS

In the United States, intercity trucking has carried one-fifth of all intercity freight transported, measured on a ton-mile basis. Some projections to 1990 actually show trucks surpassing railroads in total freight carried. To handle the diverse commodities shipped by truck, a wide variety of special sizes and configurations in vehicles has been developed. To a considerable degree the combination of special components can be specified by prospective buyers. Trucks are typically classified by gross vehicle weight, and only the two heaviest classes (Class VII, 26,001–33,000 pounds and Class VIII, above 33,000 pounds) are really significant in carrying intercity freight long-distance.

From an energy viewpoint, freight transportation is expected to consume an increased portion of transportation energy, rivaling the automobile by 1990 and thereafter. As a consequence, the energy efficiency of the freight system is likely to become increasingly important and may be a significant factor in future changes in freight transportation.

Because larger trucks may be operated at lower costs per ton-mile to the operator and may consume less fuel on a relative ton-mile basis, there have been some recommendations that size and

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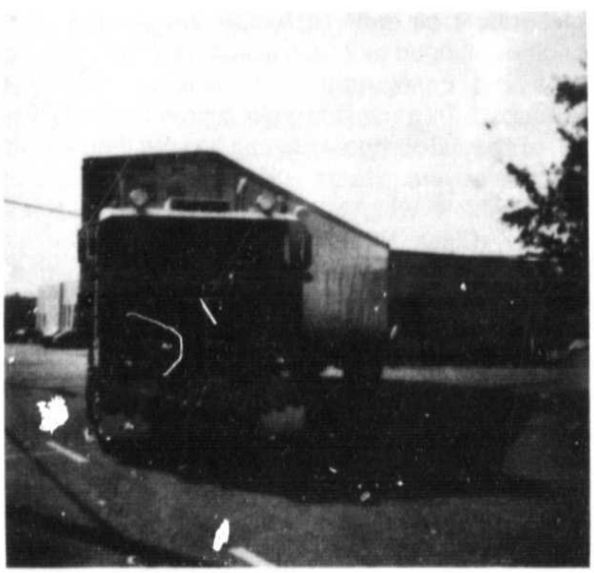
weight restrictions on larger trucks be modified to allow use of the more efficient sizes.

Use of larger trucks raises several safety issues. The splash and spray effects of large commercial vehicles, especially at speeds over 50 miles per hour, can be annoying and, perhaps, even hazardous to auto drivers. This factor may become especially important as passenger cars shrink in size in the push for improved fuel economy. The safety performance of the larger vehicles is being examined, and questions have been raised about increased requirements for maintenance of roads with extensive heavy truck usage. It has not yet been determined whether large trucks pay their full share of costs for constructing and maintaining the Federal-aid highway system. Studies are underway to address these issues.

It is not clear what effect larger trucks will have on the railroads. If competitive traffic is diverted from railroads, their ability to supply service even to traffic not amenable to truck transport may be impaired.

A number of improvements can be made to the truck itself. Available technology engine improvements can reduce a truck's fuel consumption by 7 percent. Use of a fan clutch could produce a 6 percent reduction. Many carriers have reduced fuel use by 4 percent by placing an airshield or deflector on top of a tractor-trailer cab to smooth airflow over the trailer. Even a simple action like switching to radial tires improves large truck fuel economy some 6 percent.(9) (These economy improvements are not additive.)



Motor carriers will continue to transport a large portion of the country's intercity freight shipments.

In the longer term, truck-train systems, either on reserved highway lanes or special separated roadways, might evolve, especially if competing railway service continues to decline, and intercity trucks have to begin carrying more bulk commodity shipments.(79)

It is likely that trucks will maintain their major role in small package delivery and urban goods movement. If auto congestion continues in downtown areas, pressures may develop to confine truck loading and unloading activities to night hours in population centers.

In addition, trucks have developed a reputation as a major source of noise and pollution on urban highways. However, significant reductions in truck noise have already been realized. Research on alternative methods of quieting trucks continues, as does examination of the emissions problem.

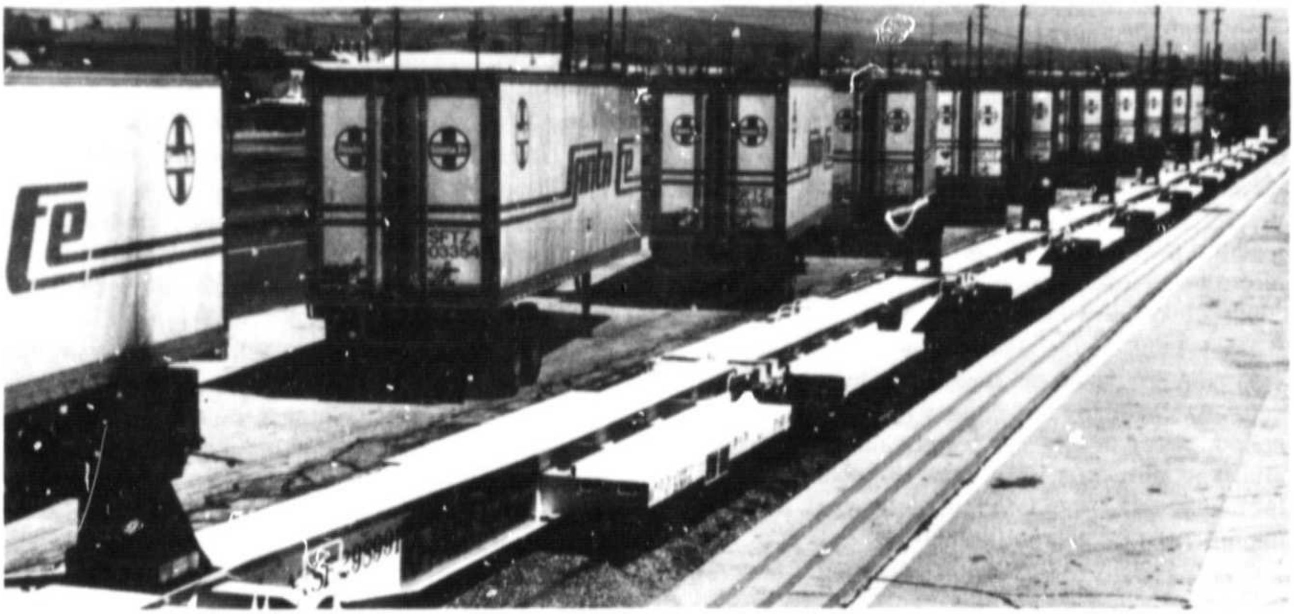
RAILROADS

Railroads are currently the primary mode for movement of intercity freight traffic in the U.S. on a ton-mile basis. The current 200,000-mile network of rail in place in the U.S. moved about 37 percent of the total revenue freight ton-miles shipped in 1979. However, rail's market share of the intercity freight market has been declining. The advantages once held by rail in moving bulk commodities have been eroded by pipeline and barge traffic. Trucks have also made inroads into rail markets, aided by the Interstate Highway System and their potential for service flexibility. These current trends may be strongly influenced in the future by the cost of fuel per ton-mile, which may slow or reverse the trend to truck use.

Like rail passenger service, rail freight may grow in importance if major petroleum shortages occur. Intermodal services offering high efficiencies may expand, alternative energy sources may be applied, and advanced technologies such as fuel cells, gas turbines, Stirling engines and others may be incorporated into locomotive designs.

Many of the problems of the rail industry in the U.S. have been attributed to regulation complexities. Hopefully, the Staggers Rail Act of 1980 will help to lessen these types of problems by promoting competition, eliminating some regulatory barriers, and reducing red tape.

Poor service, in terms of both shipment time and reliability, and poor productivity of existing equipment are two major problems of rail operation that continue to plague rail carriers. An extensive amount of time is spent separating and reassembling cars into new trains in intermediate yards. Delays associated with repeatedly separating the cars of existing trains and reassembling them into new ones with different destinations contributes to long delivery time. It also compromises the reliability of service.(73)



10-pack fuel foiler services could take on added importance in the future.

Recently, however, railroads have been making advances in car scheduling systems. For example, the Missouri-Pacific (MoPac) Railroad Company has developed a Transportation Control System (TCS) with the strong support of the Federal Railroad Administration. With its TCS automated scheduling system, cars have been moving through the MoPac's major Chicago terminal about one-third faster than before TCS was introduced.

Another approach to the yarding problem might be to schedule more and shorter trains which operate at higher frequencies and require fewer intermediate stops. This strategy would imply an increased use of automation, although not necessarily a reduction in personnel since more trains would require more crews. Further use of advanced computer technology for freight car scheduling will improve the efficiency of railroad freight operations and reduce costs. Efficiency improvements are expected in the areas of yard and terminal switching, transit time, and train schedule planning.

There has been an increased use of intermodal services which may accelerate in the future. Intermodal traffic, including trailer-on-flat-car (TOFC) services with trucks or container-on-frame-car (COFC) services with a variety of modes, second only to coal in rail carloadings, increased 3.2 percent in 1979 over 1978. Another important intermodal service includes transfer of bulk goods between rail and barges. The Southern Railway's Pride, Alabama, facility is an example of such an efficient coal loading facility that transfers coal from barge to rail unit trains.

New hardware for intermodal operations is also becoming available. For example, the Santa Fe Railway's Ten-Pack Fuel Foiler weighs 35 percent less than a conventional train of equivalent carrying capacity. Such a car would produce fuel savings of about 15 percent or 6,000 gallons for a round trip between Chicago and Los Angeles.

AIR CARRIERS

Domestic air cargo carries less than one percent of all freight movements; however, air cargo is a rapidly growing industry. Air generally provides the lowest door-to-door transit time for shipment distances over 600 miles. However, direct truck service is generally quicker than air for distances under 500 miles and remains somewhat competitive for shipment distances up to 800 miles. Compared to truck shipments, air is relatively high cost and has typically been used for shipment of relatively small, high-value packages with a time premium. For longer distances, especially international, air is used for a wider range of commodities.

Several options are currently used for the shipping of freight by air. Narrow-bodied freighters are used in three major applications: charter flights, scheduled operations of all-cargo carriers, and combination passenger-cargo carriers. Wide body passenger jets carry cargo in their lower holds, and some wide body jet freighters have entered service.(84)

If current trends continue, cargo aircraft developed between now and the year 2000 will most likely be derivatives of large passenger air-

craft. With the same trends pushing for an increase in freight as well as passenger airliner size, the trend toward jumbo jets should continue. Very large aircraft, with payload weights up to a million pounds, may develop. These large freighters should be equipped to handle intermodal containers as well as current freight types There is also the possibility that joint military/civilian cargo aircraft may evolve, depending on the direction of research in these fields.

Realization of the potential of air cargo to provide unique service characteristics, such as schedule reliability and special handling as well as speed, depends heavily on the solution of ground interface problems. Problems of ground access, terminals, custom clearance, paper work and containers must be given attention.

The possibility of using lighter-than-air (LTA) craft as heavy lift freighters has also been discussed. The most promising concept is one combining buoyancy and rotors for propulsion and control. It would be used for very short haul cargo transfer or precision vertical lift of heavy or outsize items. The principal one is a heavy vertical lift for use in short haul operations such as ship-to-shore cargo hauling, logging, power line construction, remote area resource development, and high rise construction.(4) Another use would be in low speed, long endurance patrol missions. These vehicles also may be useful for military and law enforcement applications, particularly if maneuverability requirements are emphasized in the design. Long-haul freight transportation by LTA appears to be uneconomical at present.

MARINE AND WATER CARRIERS

Maritime transportation should maintain a continued importance in domestic freight movement and should remain predominant in our foreign trade (up to 90 percent of the total foreign trade tonnage). The U.S. grew largely because of rivers and canals, and its ports located on rivers, the Great Lakes, the Gulf and sea coasts. Inland waterway commerce is maintained, in large measure, by river towboats, barges, and Great Lakes grain and ore carriers; foreign commerce is maintained almost entirely by freighters and tankers. (It should be noted, however, that only a portion of foreign commerce is carried on U.S. Flag carriers.)

Most of today's river traffic and much of the coastwise trade is carried in towed or pushed barges. Modern freighters, including large containerships and vanships, also operate routinely in the offshore domestic trade. Tug-barge services are especially useful for low-cost movement of bulk commodities where speed is of less importance. Deep draft vessels of up to 730 feet long utilize the entire Great Lakes St. Lawrence Seaway System, and bulk carriers of up to 1,000 feet long operate in the Upper Great Lakes above the Welland Canal.

Petroleum use in marine systems might be reduced by a variety of techniques, including the application of waste heat recovery systems and the use of alternative non-petroleum fuels such as synthetic fuels, alcohols, and coal.

Domestic waterborne commerce has been improved significantly—and there is potential for much greater improvement—through intermodalism, which integrates all modes of freight movement (water, rail, highway, and, to a limited degree, air) including shipments via shallow-draft vessels. Containerization initially linked these transportation modes. Lighter-aboard-ship (LASH) vessels, Seabee barge carriers, and vanships have further expanded intermodal shipping services. (It should be noted, however, that some of the shipping lines employing LASH/Seabee have reassessed this decision.)

Barge-carrying ships take loaded barges aboard and transport the entire assembly to the port of destination where the offloaded barges carry the cargo into confined waters, beyond deepwater ports. The versatile barges carry all types of cargo, including containers. They give an extra dimension to intermodalism and are readily adaptable to cargo-handling constraints encountered in ports of developing countries.

The 1970s trend toward larger oceangoing ships appears to have slowed, although larger dry-bulk ships and intermodal ships are likely to develop. There is continuing pressure to develop deepwater ports and other specialized facilities needed to serve these larger ships.

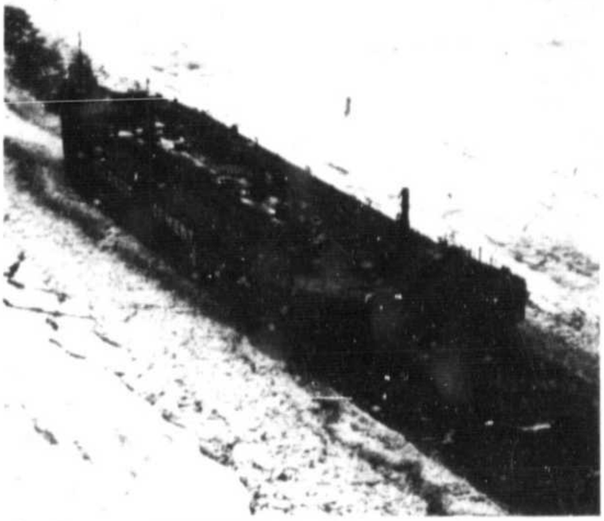
Some of the new freighters and tankers could possibly be nuclear-powered, although institutional and environmental constraints would appear to preclude this for the foreseeable future.

Energy transportation, particularly the significant increase in coal movements in domestic ports, on domestic waterways, and through coastal ports, is already having an impact. Given the draft limitations of many coastal ports, serious consideration is being given to the construction of offshore port complexes. Offshore ports would be able to serve deep draft vessels that cannot currently enter U.S. ports, thereby enhancing transportation efficiency. As noted in the *Interim Report of the Interagency Coal Export Task Force*, transportation costs are a significant portion of the costs of exported coal.(53) It is believed that unless

there is a fairly rapid expansion of port capacity in many areas, export markets for coal may be lost to other producers. As an alternative to offshore port complexes, a number of channel-deepening projects at existing ports are being considered.

All signs point to the extraction of the vast petroleum reserves known to exist in the Arctic, and new marine systems will be needed to transport this cargo. Over the near term, large ice-breaking tankers will be used. In the next century submarine tankers might be used in this area.

Since large quantities of petroleum and hazardous cargos are transported by water, there should be a large increase in the number of vessels having double hulls and other special configurations to reduce the possibility of accidental spills. Vessels that navigate in ice-covered waters will have ice-strengthened hulls, higher shaft-horsepower, air bubbler systems, and other specialized devices. An enhanced marine transportation system that is safe, efficient and provides adequate protection for the environment will be required.



Arctic operations may become increasingly important in marine freight movement.

Some of the major technological contributions that will bring about an increase in productivity in water transportation will be improvements in cargo handling at ports and terminals. Improvements in the area of intermodal transfer appear to offer wide opportunities for an application of technology to improve productivity.

Several port and waterway expansion projects have experienced long delays associated with the disposition of dredged materials. Conflicts also arise with respect to land and water use near port complexes, particularly when there is a desire to expand the area of a port. Issues raised include preserving sea lanes, protecting fishing rights, and developing oil or mineral potential in the same area. Technological applications, such as improvements in navigation systems and in guidance and warning systems, could help to resolve some of these conflicts.

To improve vessel fuel economy, coal as a fuel source is being explored. Coal-powered vessels are already on order or in use in Japan and Australia, primarily in coastal trade. It is highly probable that by the turn of the century a significant amount of world merchant shipping will be fueled by coal.

For smaller vessels, and primarily the inland river transportation sector, liquid fuels derived from coal and shale can be expected to be the major source of fuel. It is possible, however, that alcohol/methanol fuels derived from waste products and vegetation may be introduced as a fuel for this sector. By the turn of the century, the application of hydrogen storage system (hydrides) to small domestic waterway vessels is distinctly possible.

The primary constraints on water transportation in domestic waters are expected to occur at certain locks. Key locks that will require capacity expansion over the next 10 to 20 years are Locks and Dam 26 on the lower Mississippi River, Gallipolis on the Ohio River, the Inner Harbor Locks on the Gulf Intercoastal Waterway and the Canadian Welland Canal connecting Lake Erie and Lake Ontario. Other locks that might become capacity constraining include those at the Calcasieu on the Gulf Intercoastal Waterway, and Demopolis on the Warrior River.

Ocean thermal gradient energy conversion (OTEC) plants, in which energy would be produced as a derivative of the difference in ocean temperatures, might one day be built near shore or on the Outer Continental Shelf. If so, a transportation system to support these plants would become necessary.

In addition to OTEC plants, coal-based or nuclear generating plants located in coastal waters near population centers might be constructed. If these offshore power plants are successful, power-intensive processing facilities might be placed offshore, on either fixed or floating platforms. Barge-mounted plants have already been constructed to liquify natural gas. Designs exist for barge-mounted processing plants to produce ammonia, urea, alcohols, aluminum, and woodpulp.

Locating such energy-intensive plants offshore may result in lower cost output since it would

eliminate the necessity of transmitting needed power to shore. Locating chemical plants offshore would also reduce the danger from explosions and fire and would free onshore sites for other purposes. The establishment of such offshore plants would require a marine transportation system to support the movement of goods and personnel to and from the sites. In addition, offshore mining of minerals in deep ocean areas is anticipated in the near future. Vessels having several special features will be needed to accomplish this mining operation.

Wind augmented vessels, the descendents of sailing ships, may prove economically viable once again as the cost of fossil fuels continues to increase. Applications discussed include large ocean tankers and other bulk carriers. New sail forms, new materials, satellite weather information, and computerized operating systems to control the number and positions of sails may make such vessels effective and efficient in some maritime trades.

Hydrofoils or large oceangoing hovercraft may also see some cargo application, but there have been few U.S. efforts recently to develop them.

PIPELINES

The pipeline mode will probably continue to evolve, maintaining its important role in the delivery of liquid and gaseous products. The Alaska oil and gas pipelines are illustrations of the opportunities and problems this approach presents. Slurry pipelines, where powdered solids are mixed with a liquid, pumped through pipes, and the liquid extracted at the destination, are also receiving considerable attention in the United States for moving coal from land-bound mines to power generating stations and oceanship loading docks. However, this approach requires a plentiful supply of liquid (usually water) at the origin of the pipeline. Institutional problems with coal slurry pipelines relative to the railroads have also been raised.

Another emerging technology which may see application is the pneumatic capsule pipeline. Under this approach, shipments are placed in closed standard containers and propelled through a large pipeline by air pressure. Small-scale systems of this type have been in use for years, and some pilot or test systems have also been built using the larger-scale technology.

Chapter 7
Space Transportation

Spacecraft evolution has been one of the fastest developing transportation areas. It was only twelve years from the orbiting of the first earth satellite to the first manned landing on the moon, and only twenty years between the flight of the first human in space, Yuri Gagarin, and the Space Shuttle. Between the direct impacts of satellites and other orbital systems (for example, intercontinental television, remote sensing, and improved weather forecasting), and the indirect impacts of technologies developed for the space program (for example, microcircuitry, advanced insulation, and new plastics and synthetic material), life styles worldwide have been profoundly altered. Improvements in navigation for air and marine systems have already resulted from use of satellite systems, and further improvements are probable. This section will provide a very general overview of some ongoing programs for spacecraft development and note some of their longer term implications.

THE SPACE SHUTTLE

The Space Transportation System, or Space Shuttle as it is more familiarly called, is being developed as the world's first manned reusable spacecraft. Its successful first flight in Earth orbit, April 12 to 14, 1981, will be followed by longer and more complex missions, leading to full operational capability. Each craft is designed to be orbited some 100 times and is to be capable of carrying from the Kennedy Space Center in Florida a 65,000-lb. payload into a 240-mile high due-east orbit.

The Space Shuttle consists of four major elements. The heart of the system is the orbiter, a rocket plane about the size of a DC-9 which can be flown into, and back from, earth orbit. During takeoff, the orbiter rides upon a 27-foot diameter, 155-foot long tank which carries much of its fuel. The fuel used for these flights is liquid hydrogen with liquid oxygen as an oxidizer. The tank is the only part of the vehicle which is not recoverable. To provide additional needed thrust during liftoff, two solid propellant boosters of 2-½ million pounds thrust each are attached to the fuel tank. Total weight of the vehicle at takeoff is some 2,000 tons.

The orbiter's structure is primarily aluminum. It relies on a different heat protection approach than the ablative materials (which char, carrying away heat) most re-entry vehicles have used. In particular, the nose and wing leading edges of the vehicle are covered with carbon caps. Ceramic-coated silica fiber tiles, weighing no more than balsa wood, are used to protect the rest of the vehicle.

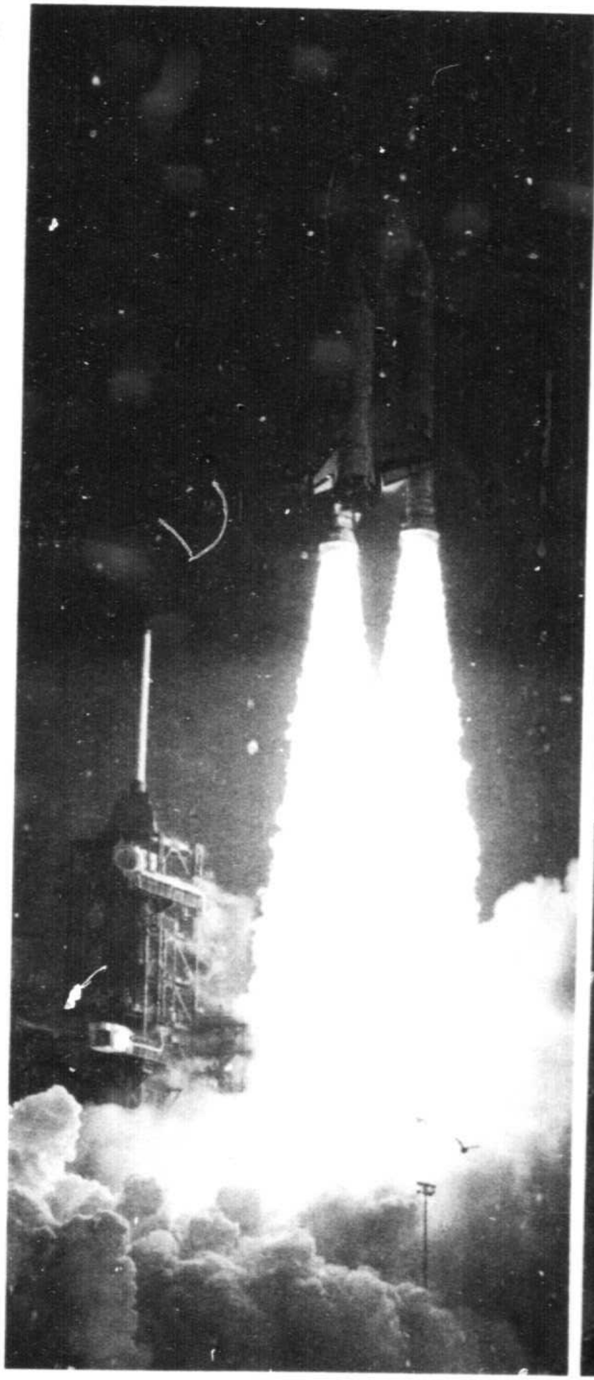
The large size and flexibility of the orbiter provide a number of advantages conventional launch vehicles have not had. Not only can it carry payloads to and from orbit, it also is capable of in-orbit operations. The orbiter's payload bay is some 60 feet long and 15 feet in diameter. As a result, many of the weight and volume constraints imposed on previous spacecraft payloads could be relaxed. Since the orbiter is manned, the vehicle can rendezvous with satellites already in orbit in order to repair or refurbish them. If necessary, satellites can even be retrieved by the orbiter and returned to earth for reuse or repair. Considerable cost savings may result from such reuse.(3)

To place payloads into higher orbits, the packages can be equipped with upper propulsion stages. In this approach, the payload is lifted by the orbiter into low orbit, set into space, and its engine ignited to place it on the desired trajectory.

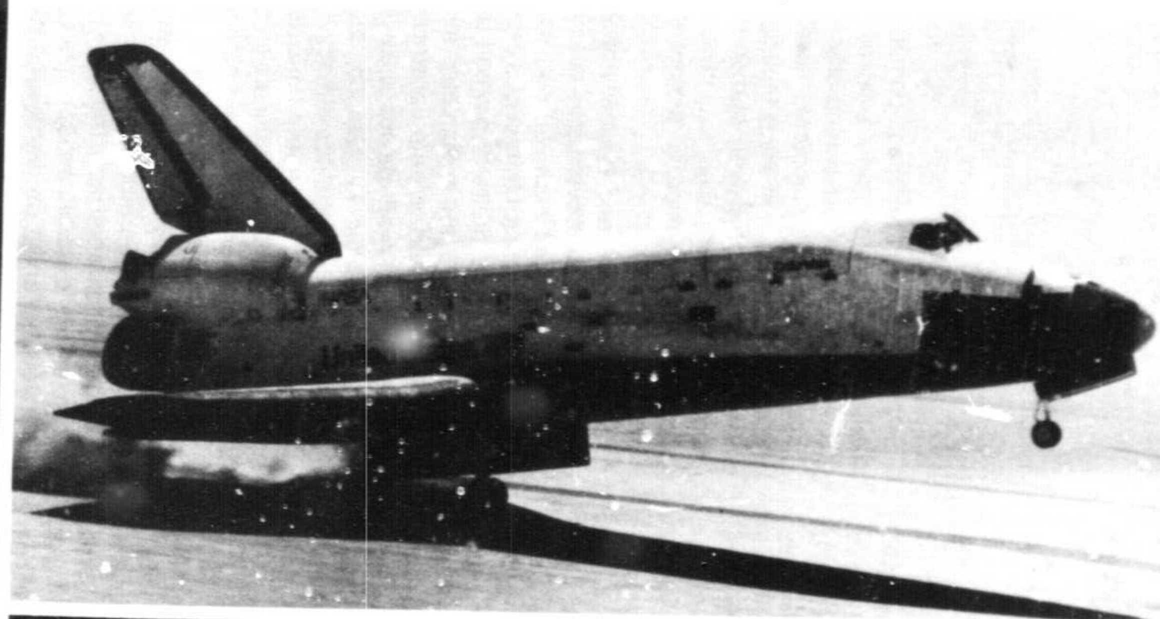
The basic Space Shuttle mission is limited to seven days in orbit. However, with extra provisions and a smaller payload, longer duration flights can be conducted with a standard Space Shuttle configuration.

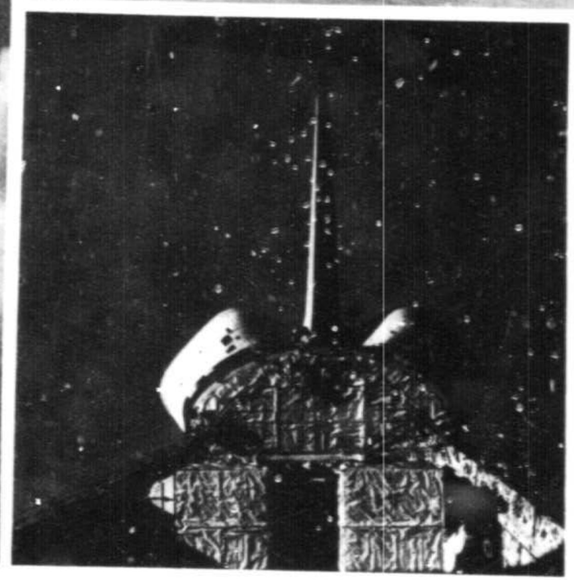
FUTURE ORBITAL SYSTEMS

The Space Shuttle is the first step in the possible evolution of an advanced family of manned orbital systems. Several options are open, none of which rule out the others except on resource grounds. For example, one approach might be to upgrade the existing shuttle, substituting a new fly-back booster as first stage for the solid rocket boosters. This new large booster vehicle could then serve as the basis for the development of a new, larger orbiter.



NASA's Space Shuttle **Columbia** First Launch, April 12-14, 1981





LEFT: The successful launch of the Space Shuttle "Columbia", STS-1, first in a planned series of reusable Space Transportation System vehicles, on April 12, 1981, just past 7 a.m., EST. **CENTER:** The touchdown of Columbia and her crew, Astronauts John Young, Commander, and Robert Crippen, Pilot, on April 14, 1981, after 54½ hours in orbit. **LOWER LEFT:** The cargo bay of Columbia, its doors open, during orbital testing on April 12 and 13, 1981, establishing its readiness to carry future payloads to and from Earth orbit.

National Aeronautics and Space Administration

Another approach would be to undertake development of a single stage to orbit (SSTO) shuttle vehicle. This vehicle, which would probably be hydrogen-fueled, could fly directly from ground into earth orbit without requiring staging of additional boosters. A number of launching options are open for such a vehicle, including vertical takeoff like the current shuttle, horizontal takeoff from a rocket sled or catapult, or some type of in-flight refueling before trying for orbit.

Once Shuttle operational capability has been achieved, deployment of a long-duration orbital manned "space operations center" or "space station" might be possible. An operations-oriented space station could be launched by 1989. Assembled from modules carried up by two to four orbiter flights, it would allow continuous operation in low orbit by a crew of three to eight.

A project under consideration for earlier flight involves using a "Kilowatt (KW) power system" to support an unmanned space platform for science and applications missions. The power system would provide solar-generated electric power and attitude control for the vehicle. It would be carried into orbit by the Shuttle and deployed there by the vehicle. Also under investigation for the mid-80s are the components of a Space Platform that combines science and applications payloads on a common structure. Such a device could be unmanned except when being serviced, or a "habitability" module could be added, allowing continuously manned operations. In either case, this would open the way to large-scale construction projects in orbit.(8)

In the longer term, especially if large construction projects are contemplated, there may be need for a heavy-lift (multimillion pound thrust) freighter. The various stages of this vehicle would have to be recoverable and reusable, but the payload might only have to reach orbit and not have a re-entry capability. This is especially true if it merely serves as packaging for a construction project being assembled by shuttle or advanced shuttle crews. (19) For the nearer term, unmanned variants of the Shuttle are also being investigated. They could provide either launch capability for larger and heavier payloads, or simpler, reliable and low-cost backup to the Shuttle. Extensive use may also be made of "free- flying teleoperators" (remotely operated service units) to position and work with the materials once in orbit. The development of an Orbital Transfer Vehicle (OTV)—first unmanned, then manned, would allow the extension of permanent occupancy of space to various high orbits.

Such major orbital construction projects might include the development of a large telecommunications platform or, eventually, a series of large solar collection satellites in geosynchronous orbit (that is, one orbit takes one day at 22,300 miles, and the satellite appears to hover over one point on the Earth's surface).

Studies of advanced shuttle applications in the next 30 years reveal that major developments in the industrialization and commercial utilization of space will focus on four main areas: remote sensing, new information/communication services, new materials and products "made in space," and solar-generated energy in and from space. To meet these anticipated needs of space industrialization, the Space Transportation System will be further developed in an evolutionary program that allows for increased performance, enhanced utility, and a broadened range of support services, and eventually leads to permanent occupancy of space by man.(98)

DEEP-SPACE SYSTEMS

Manned craft should eventually follow the unmanned probes which have gone out to the planets and stars. A wide variety of technologies have been proposed for these missions, some of which are fairly exotic. Because of the projected long travel times for these trips, nuclear power is frequently proposed as their energy source. Among the engines which have been proposed are ion rockets, which accelerate charged atoms to high velocity using an electrically charged grid. Even huge solar sailing ships, driven by light pressure on their thousands of square feet of "sail," have been examined.

Conclusion

This report has dealt with some of the technologies which probably will be prominent over the next three decades. However, the broader impacts of these technologies are just as important, if not more so. State and local officials, after all, are interested ultimately in the social and economic well being of their jurisdictions. As a result, many are concerned with transportation primarily as an instrument in achieving broader goals.

These broad societal impacts of technologies are difficult subjects to learn about. However, the time which is required to develop and perfect the longer term options described here also gives us time to develop the more sophisticated understanding needed. We are not restricted to what is known now, and have the option to evolve new approaches to structuring our society.

The decision-making climate in this country is going through some major changes, too. A concern that each level of government take its appropriate role in the solution of societal problems has developed and may lead to substantial realignments in the process by which choices are made. This will put an added importance on informed decision making in state and local governments.

All of these writeups have been based on evolutionary developments from existing technologies. As was noted previously, a true breakthrough in any area could completely redirect the course of transportation futures. Some of the final technology choices for new systems may be decades in the future. The key is, therefore, to watch the various options as they evolve, and reflect them intelligently in implementation plans.

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